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LANDSAT 4 TO GROUND STATION INTERFACE DESCRIPTION

REVISION 5

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

REVISION PAGE

REVISION	DATE	BY	DESCRIPTION	APPROVED
Revision 1	5/28/81			W. Webb
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PREFACE

Revision 5 of the Landsat-D to Ground Station Interface Description represents an update of the Revision 4 document published in February 1982.

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ACRONYMS

ACS	Attitude control system
A/D	Analog to Digital
ADS	Angular displacement sensor
ADSA	Angular displacement sensor assembly
BER	Bit-error ratios
BCD	Binary-coded decimal
BIO-M	Biphase mark
BPSK	Balanced PSK
Cal	Calibration or calibrate
CCT	Computer-compatible tape
CMD	Command
CU	Control Unit
dB	Decibel
dbw	Power in decibels, referenced to 1 watt
DEMUX	Demultiplexer
Domsat	Domestic communications satellite
DPU	Digital processing unit
DRIRU	Direct readout infrared radiometer unit
ECI	Earth-centered inertial
EOL	End of line
EP	Euler parameter
EROS	Earth Resources Observation Systems
FS	Flight segment
FPA	Focal-plane assembly
GMT	Greenwich mean time
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking Data Network
HDT	High-density tape
ID	Identification
IC	Internal calibration
IFOV	Instantaneous field of view

ACRONYMS (Continued)

IRU	Inertial reference unit
kbps	Kilobits per second
L/F	Low frequency
LGSID	Landsat-D to Ground Station Interface Description
LGSOWG	Landsat Ground Station Operations Working Group
LSB	Least significant bit
MBPS	Megabits per second
MFID	Minor-frame ID
MHz	Megahertz
MMS	Multimission Modular Spacecraft
MNFS	Minor-frame synchronization
MSB	Most significant bit
msec	Millisecond
MSS	Multispectral Scanner
MUX	Multiplexer
NASA	National Aeronautics and Space Administration
NETD	Noise equivalent temperature difference
NRZ	Nonreturn to zero
NRZ-M	Nonreturn to zero mark
OBC	Onboard computer
OCC	Operations Control Center
PCD	Payload correction data
PDU	Power distribution unit
PM	Phase modulated
PN	Pseudonoise
PN	Not PN
PSK	Phase-shift keyed
RAD	Radian
RIU	Remote interface unit
RMS	Root mean square
SAM	Scan angle monitor
SLC	Scan-line corrector

ACRONYMS (Continued)

SLS	Scan-line start
SMA	Scan mirror assembly
SME	Scan mirror electronics
S/N	Signal to noise
S/NR	Signal-to-noise ratio
TBD	To be determined
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TGS	Transportable Ground Station
TLM	Telemetry
TM	Thematic mapper
TWX	Teletype message
UQPSK	Unbalanced quadrature phase-shift keyed
UTC	Universal Time, Coordinated

LANDSAT-D TO GROUND STATION INTERFACE DESCRIPTION

1. LANDSAT-D MISSION OVERVIEW

1.1 FLIGHT SEGMENT

Figure 1 is an illustration of the components of the Landsat-D flight segment.

1.2 ORBIT

The Landsat-D orbit is defined as follows:

Altitude	705.3 km
Inclination	98.2 degrees
Repeat cycle	16 days
Orbits per cycle	233
Ground trace spacing at Equator	172.0 km
Sidelap at Equator	7.6 percent
Descending node time	0930 to 1000 hours
Nodal period	5933.0472 seconds

The value of 705.3 for the Landsat-D orbit agrees with the altitude over the Earth's Equator (h_e) that satisfies a Keplerian period (P) corresponding to the design nodal period. The 705.3-km altitude is not intended for use in detailed orbital analyses because it does not precisely represent the actual Landsat-D altitude at the Equator.

a is altitude measured from the center of the Earth.

$$P = 2\pi\sqrt{\frac{a^3}{\mu}} \quad P = 5933.0472 \text{ sec}; \mu = 398601.2 \ \frac{\text{km}^3}{\text{sec}^2}.$$

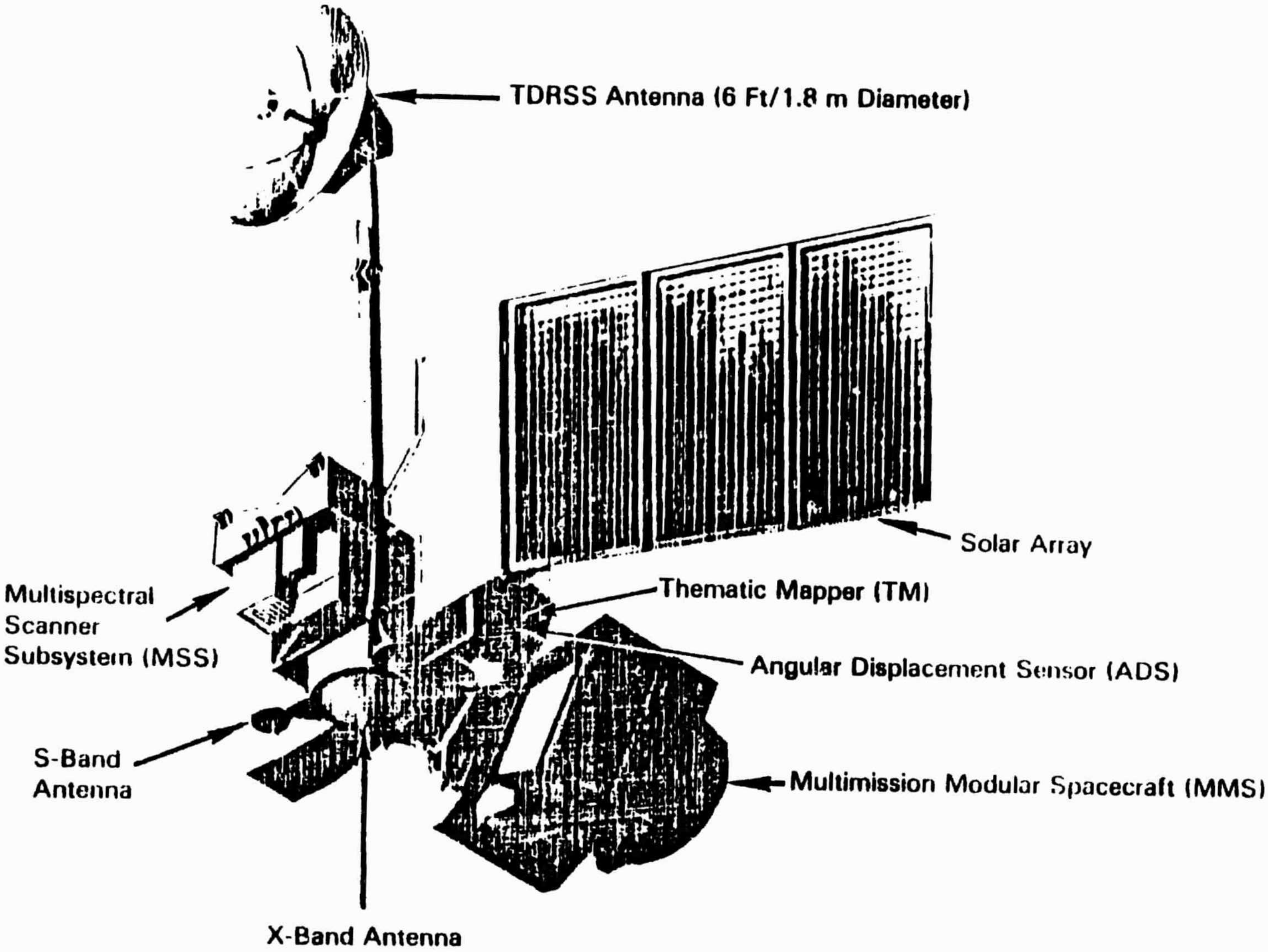

Figure 1. Landsat-D Flight Segment

$a = 7083.465$ km, $r_e = 6378.165$ km.

$h_e = a - r_e = 705.3$ km.

Figure 2 shows the Landsat-D orbit for the 16-day period. Maps and information regarding nominal ground track and scene-center locations for Landsat D will be available from the Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota.

1.3 FUNCTION OF LANDSAT-D ATTITUDE CONTROL SYSTEM

The Landsat-D spacecraft attitude control system (ACS) orients the spacecraft relative to a desired target. The central control system element is an onboard computer (OBC) that processes all sensor-derived information and, in conjunction with various types of stored information, generates the appropriate control signals to operate the spacecraft reaction control devices. The Landsat-D reference sensor system consists of coarse Sun sensors, an Earth sensor (for safe-hold only), an inertial reference unit (IRU), a pair of fixed-head star trackers, and a three-axis magnetometer. All sensor outputs are transferred to the OBC in addition to being downlinked in telemetry. The OBC processes the sensory inputs and derives the control equipment commands. The primary attitude reference is derived from the IRU. The IRU bias drift and scale factor errors are computed within the OBC through use of known target stars. A 1-sigma pointing accuracy of 0.01 degree is expected from this system.

1.4 COMMUNICATIONS

Figure 3 shows the overall data flow from Landsat-D. Foreign ground stations will receive data by X- and S-band links. For more information concerning these data transmissions, refer to Section 9.

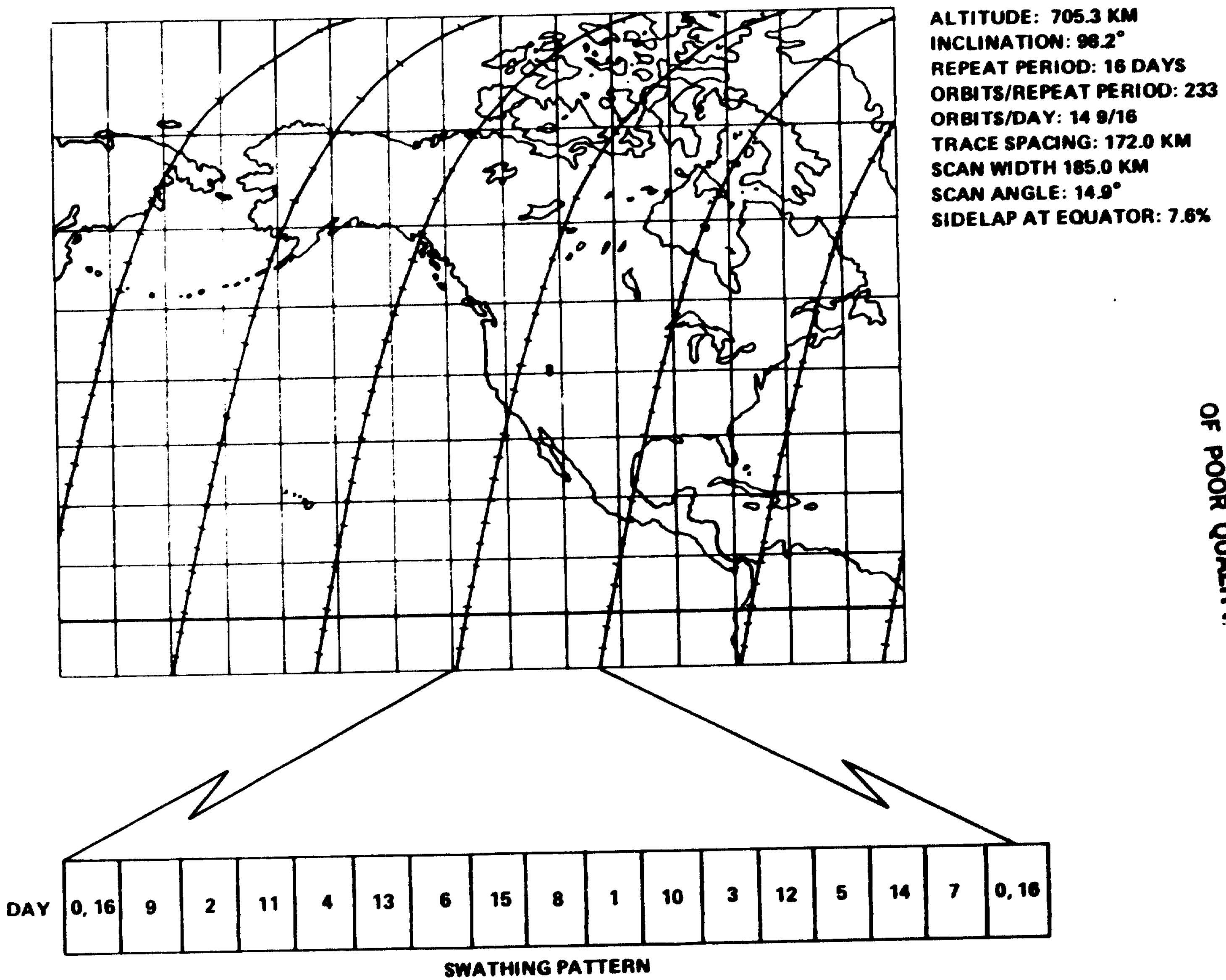

Figure 2. Swathing Pattern for One Satellite (16-Day Coverage)

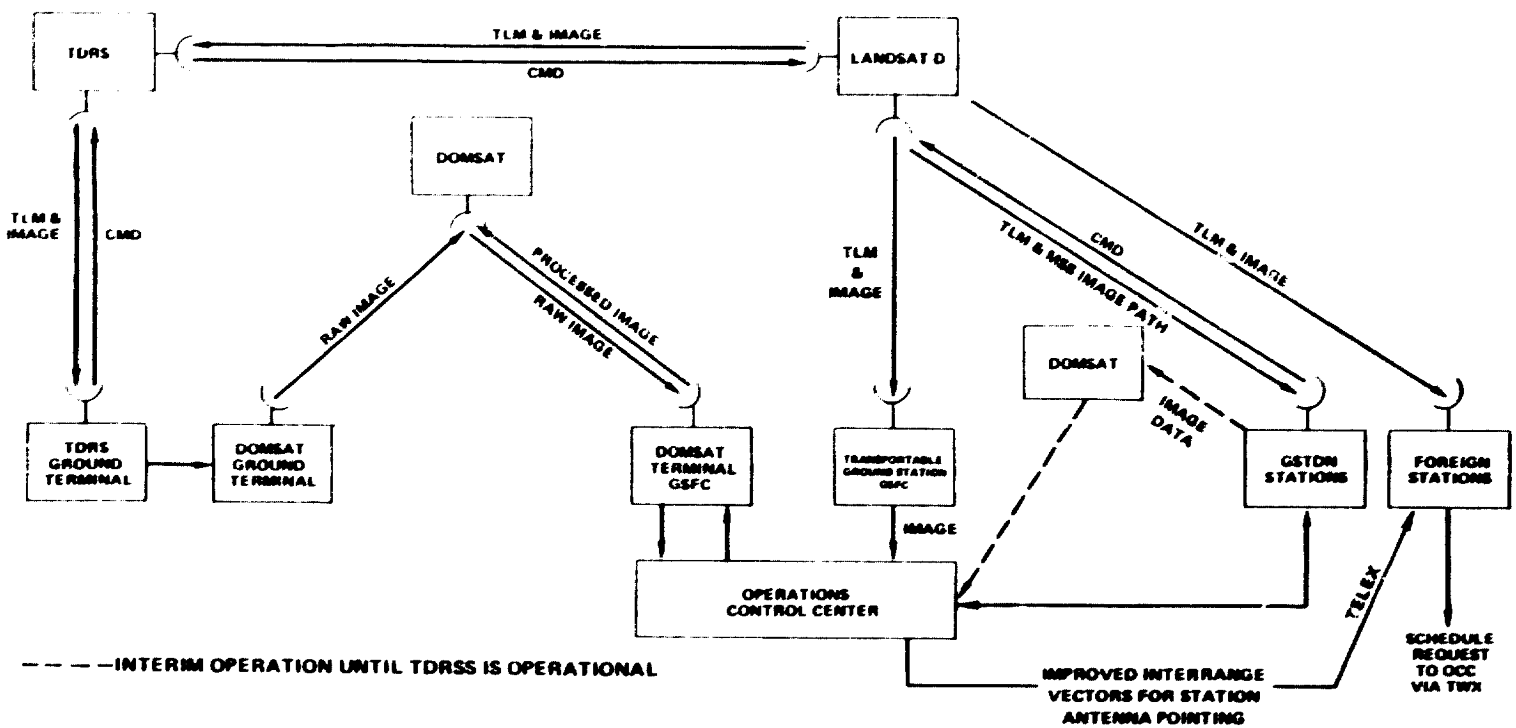

Figure 3. Landsat-D Overall Data Flow

1.5 NASA/GODDARD SPACE FLIGHT CENTER (GSFC) LANDSAT-D USER PRODUCT SPECIFICATIONS

a. NASA/GSFC intends to maintain the Landsat-D Data Management System MSS partially processed output high-density tape (HDT-A) format compatible with the Landsat 3 format family currently in use within the GSFC/Image Processing Facility.

b. MSS user photographic and computer-compatible tape (CCT) products will not be produced by GSFC. Earth Resources Observation Systems Data Center will be responsible for producing these user products.

c. The TM high-density tape (HDT), CCT, and photographic output product formats have not been defined. However, plans are being made to conform the formats as closely as possible to the generic structure of the HDT and photographic products currently being used for Landsats 2 and 3. GSFC intends to use the Martin Marietta Model MH2879-L high-data-rate recorders and the Goodyear Landsat-D high-resolution film recording system.

Additional product information should be obtained from the EROS Data Center, Sioux Falls, South Dakota.

2. ATTITUDE AND EPHEMERIS DATA

NASA/GSFC plans to provide attitude and ephemeris data to Landsat Ground Station Operations Working Group (LGSOWG) members on a routine basis within the telemetry S-band downlink and TM video data. The ephemeris data, which are provided in the form of orbital-state vectors, will be derived from uplinked predicted ephemeris data.

The ephemeris position accuracy is presented in Table 1. The content and data format are described in Section 5. The ephemeris data

provided within the telemetry S-band downlink and TM video data will normally be between 1 and 2 days from tracking data cutoff. Onboard ephemeris processing by the OBC does not introduce any significant degradation to the accuracies defined in Table 1.

Table 1
Ephemeris Location Accuracy
(1 sigma)

Source	Position/Location Accuracy (meters) (days from tracking cutoff)		
	1	2	3
Predicted-fit ephemeris	250	500	1000

Landsat-D pointing accuracy will be 0.01 degree (1 sigma). Pointing, ephemeris, alignment of the TM to the pointed axis, and timing errors will result in positional accuracy of the imagery with systematic correction only (no use of ground control points) as summarized below:

Error Source	Cross Track (Meters 1σ)	Along Track (Meters 1σ)
Ephemeris	100	500
Time	N/A	80
Attitude	123	123
Alignment	427	855
Total (root-sum-square)	455	1001

The altitude of the Landsat-D orbit, considering both orbit eccentricity and the Earth's figure, will vary between about 685 and 740 kilometers. Maximum altitudes will occur over the North and South Poles and minimum altitudes will occur over equatorial regions.

The Landsat-D ACS-pointed axis is defined as the line of sight from the spacecraft of the geocenter (i.e, the origin of the Earth-centered inertial true-of-date coordinate system). This is also the

nominal alignment axis for the optical axes of both the TM and the MSS. Actual alignment errors of the instruments will be calibrated in flight.

3. NAVIGATIONAL DATA

NASA plans to provide improved interrange vectors (I^2RV) by Telex which allow proper pointing of ground station antenna for acquisition of satellite data signals. These vectors will be provided daily, at least 24 hours before becoming effective. The I^2RV message is described in Appendix D.

For use in processing image data, ephemeris data are transmitted in both 8-kbps telemetry (described in Section 7) and 32 kbps payload correction data (described in paragraph 5.4.7). NASA will also use ephemeris data transmitted from the flight segment for processing image data.

4. MULTISPECTRAL SCANNER SPECIFICATIONS

4.1 MULTISPECTRAL SCANNER RADIOMETRIC REQUIREMENTS

4.1.1 Spectral Bands

The MSS operates in four spectral bands in the solar-reflected spectral region as follows:

a. Band 1--0.5 to 0.6 micrometers
b. Band 2--0.6 to 0.7 micrometers
c. Band 3--0.7 to 0.8 micrometers
d. Band 4--0.8 to 1.1 micrometers

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4.1.2 MSS Detectors

The MSS uses the following detectors in each spectral band:

a. Band 1--Photomultiplier tube (six each)
b. Band 2--Photomultiplier tube (six each)
c. Band 3--Photomultiplier tube (six each)
d. Band 4--Silicon photodiode (six each)

4.1.3 MSS Radiance/Signal Range

The scanner provides video signals that are accurately related to radiance values in each spectral band. The maximum radiance levels for bands 1 through 4 are:

Band	Maximum Radiance 10^{-4} watts cm^{-2} $ster^{-1}$
1	24.8
2	20.0
3	17.6
4	46.0

NASA has no plans to acquire Sun calibration data for the MSS.

4.1.4 MSS Quantization

Each sample is encoded into a 6-bit word.

4.1.5 MSS Signal-to-Noise Ratio (SNR)

The ratio of output signal level to root mean square (rms) noise input radiance for the scanner and multiplexer is as defined in

Table 2 when the multiplexer samples are in the linear mode. When the multiplexer compresses signals from bands 1, 2, and 3, the SNR's are as defined in Table 3.

4.2 MSS SCANNING MIRROR CHARACTERISTICS

4.2.1 MSS Geometric Accuracy

The Landsat-D MSS scan mirror is supported by two flex pivots that exert a restoring torque on the mirror. The torque is zero at approximately the center of scan. Bumpers are provided at the two ends of scan to reverse the mirror angular velocity. During the "active" scan (west to east in the spacecraft descending node) when video data are collected, the mirror is essentially torque-free except for the flex-pivot torque. During the reverse or back-scan, a torque motor applies torque to restore the system energy lost during the previous scan cycle. The mirror inertia is approximately 0.0077 slug-ft^2 and the combined spring constant of the flex pivots is approximately 4707 ft-lb per radian.

4.2.2 Scan Mirror Assembly

Sensor ground coverage perpendicular to the satellite track is accomplished by means of a flat scanning mirror oriented at 45 degrees with respect to the scene that scans about the X-axis. The following parameters define this scan mirror assembly system:

a. Scan frequency: 13.62 Hz $\pm$0.01 percent

b. Scan angle across scene: 14.90 $\pm$0.06 degrees or 0.26 $\pm$0.001 radian

c. Timing format (Figure A-2)

d. Active scan period: 32.75 $\pm$1.25 milliseconds

Table 2
Linear Mode

	Band			
	1	2	3	4
High-radiance level:				
Minimum system signal-to-noise (S/N) output (after analog to digital (A/D) conversion)	89	73	50	104
1/2 high-radiance level:				
Minimum system S/N output (after A/D conversion)	54	46	33	54

Table 3
Compression Mode

	Band		
	1	2	3
High-radiance level:			
Minimum system S/N output (after A/D conversion)	75	65	47
1/2 high-radiance level:			
Minimum system S/N output (after A/D conversion)	43	38	30

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4.2.3 Geometric Fidelity

Geometric fidelity shall be defined by:

a. Lines per scan (scanned simultaneously)--Band 1 through band 4: 6

b. Scan-to-scan line-length variation--42.0 μr, rms over 100 scans (the variation will be larger when operated simultaneously with the TM instrument)

c. Optical centerline variations--Less than 1 percent of full scan

d. Scan repeatability--Scan angle versus time is repeatable within 24 μr, rms over 100 scans after line-length correction

e. Scan nonlinearity--For the linear portion of the forward scan, the repeatable scan rate deviates by less than +2.4, -5.0 percent from the mean scan rate.

4.3 MSS INTERNAL CALIBRATION

There are provisions in the MSS for internal calibration.

4.3.1 Bands 1 through 4 Internal Calibration

The internal calibration is provided on every other mirror scan cycle (major frame). Data on the alternate cycles are black level (dc restore in band 4). A redundant source and varying neutral density filter will generate appropriate radiant levels and spectral distribution to provide internal calibration for bands 1 through 4. The internal calibration for bands 1 through 4 consists of a decreasing gray optical wedge (ramp calibrate) input of 10.2 ± 2 milliseconds duration that occurs 42.8 ± 2 milliseconds after line-start code (nominally 11 milliseconds after end-of-line code). Preflight

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gray-wedge test data will be supplied to the Landsat-D ground stations for all modes of operation. A typical gray-wedge calibration curve is shown in Figure 4. The middle two bits of the binary words are inverted as is the case for all video data.

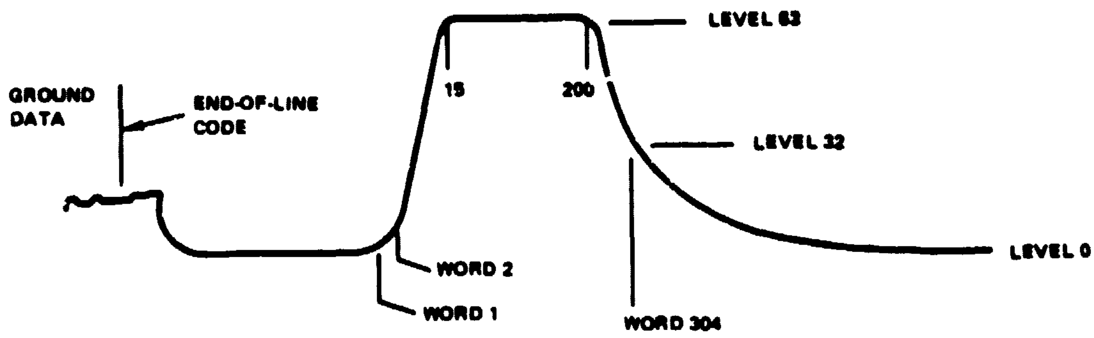

Figure 4. Typical Gray-Wedge Calibration Curve

4.3.2 MSS Internal Calibration Accuracy

For the maximum duty cycle period beginning 3 minutes after turnon (normal warmup time), the calibration wedge output provides the means to calibrate gain and offset values for bands 1 through 4 (paragraph 4.1.1) within the following relative accuracies.

a. Channel to channel (within a band)

   (1) Ratio of gains between channel: 2.0 percent peak to peak

   (2) Offset differences between channels: ±15 millivolts (less than 0.24 quantum average)

b. Band to Band

   (1) Ratio of band average gain (average of six channels) between bands: ±30 millivolts (less than 0.47 quantum level average)

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c. Stability at any channel

(1) Gain change: ±2.0 percent over the maximum duty cycle

(2) Offset change: ±12 millivolts over the maximum duty cycle period (less than 0.19 quantum level average)

The amplitude range of the calibration signal in the low-gain mode varies from a maximum of greater than 3.5 volts (level 55) to a minimum of less than 0.5 volt (level 8), and in the high-gain mode (bands 1 and 2 only) from a maximum of greater than 4.0 volts (saturated level 63) to a minimum of less than 2.0 volts (level 32).

4.4 MSS SENSOR OUTPUT FORMAT

With the exception of the addition of a 4-bit spacecraft identification word, the MSS time-code format for Landsat-D is identical to the four-band format of Landsats 1, 2, and 3. The MSS data format for Landsat-D is described in Appendix A.

4.5 MSS DATA PROCESSING CONSTANTS

The values of certain spacecraft and sensor constants required in ground processing are provided in Appendix B.

5. THEMATIC MAPPER SPECIFICATIONS

5.1 THEMATIC MAPPER RADIOMETRIC REQUIREMENTS

5.1.1 Radiometric Sensitivity

The TM output in each of bands 1 through 5 and 7 have a SNR for specified input in accordance with Table 4. For a constant input radiance, the SNR is defined as the ratio of the output value (in units of radiance) averaged over at least 100 samples to the rms

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value of the noise equivalent radiance that is defined as the rms of the deviations of the output samples from the average value.

Table 4
Thematic Mapper Signal-to-Noise Ratios

Band	Constant in Band Input Radiance (mw/cm^2-sr)	Minimum SNR
1	0.28	32
2	0.24	35
3	0.13	26
4	0.19	32
5	0.08	13
7	0.046	5

The sensitivity of band 6 is measured in terms of noise equivalent temperature difference (NETD). The NETD for band 6 as measured after at least a six-pixel settling time at 300 K is 0.5 K. The minimum scene temperature for this band is 260 K.

The TM output shall have negligible coherent noise in all seven bands for all values of radiance, including zero for bands 1 through 5 and 7. The coherent noise pattern shall be subjectively evaluated by inspecting photographic images. No coherent noise pattern shall be discernible at any radiance/signal level with the display set so that each quantizing level is visible.

The signal drift of a detector channel with a constant radiance input shall not exceed one-fourth of the rms noise of the band from one scan to the next. The maximum allowable signal-level drift after 4 minutes or less of warmup (from orbital standby temperature) shall not exceed 2 percent of full scale per 24 hours (including

five on-and-off cycles) and shall not exceed the rms noise level in any 30-second time period.

5.1.2 Radiometric Accuracy

Relative radiometric accuracy between bands operating in the reflective region shall be better than 2 percent. To maintain radiometric measurement accuracy for the total mission duration, an internal reference source is used to provide calibration data for ground correction. In addition, a dc restore technique is used on board to minimize the effects of low frequency noise and drift. A zero-radiance level is applied to the sensors when the shutters are closed to develop a zero-clamp level for the A/D circuitry. This zero-clamp level is fractionally updated before each sweep. The zero-clamp level appears as a sensor black-level output to the ground during the shutter-closed period.

NASA has no plans to acquire Sun calibration data for the TM.

5.1.3 Spectral Bands

The scanner operates in seven spectral bands in the solar-reflected spectral region as follows:

a. Band 1--0.45 to 0.52 micrometers
b. Band 2--0.52 to 0.60 micrometers
c. Band 3--0.63 to 0.69 micrometers
d. Band 4--0.76 to 0.90 micrometers
e. Band 5--1.55 to 1.75 micrometers
f. Band 6--10.40 to 12.50 micrometers
g. Band 7--2.08 to 2.35 micrometers

5.2 THEMATIC MAPPER GEOMETRIC CHARACTERISTICS

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5.2.1 TM GEOMETRY

The relationship between the Earth's surface and the data sampled by each TM detector is described in this section. The TM scan mirror is a 16- by 21-inch ellipse that provides a nearly linear scan motion covering a swath on the ground 185-km wide. A precision digital controller drives the mirror. A scan-line corrector, located behind the primary optics, compensates for the forward motion of the spacecraft and allows the scan mirror to produce usable data in both scan directions. Figure 5 shows the critical TM scanning components and the geometric relationship of the TM detectors to their ground-track projection.

Figures 6 and 7 give details of the detector geometry. The detector rows within a band are separated by 2.5 instantaneous fields of view (IFOV's). This is done because the multiplexer samples the even detectors 0.5 IFOV later than the odd detectors within a minor frame of data. In this way, the odd and even detectors are an integral multiple of IFOV's apart in space. The spacing between bands 5 and 6 is 34.75 IFOV's so that the edge of band-5 detectors will line up with the edge of a band-6 detector. Note that the band-5 detector edge is 0.75 IFOV from the center line of the band, while the edge of the band-6 detector is 3.0 IFOV's from the center line. Table 5 includes physcial spacing and sample timing. Clarification of the band 6 sampling scheme is provided in the following two paragraphs.

Immediately after the line start code, the values of band 6 Detectors 1 and 3 are held. The band 6 detector 1 sample is placed into the first minor frame after line start, and the sample of band 6 detector 3 is placed into the second minor frame. At the beginning of the third minor frame, the values of band 6 detectors 2 and 4 are held. The band 6 detector 2 sample is placed into the third minor frame, and the sample of band 6 detector 4 is placed into the fourth minor frame. The above process is then repeated starting with the fifth minor frame.

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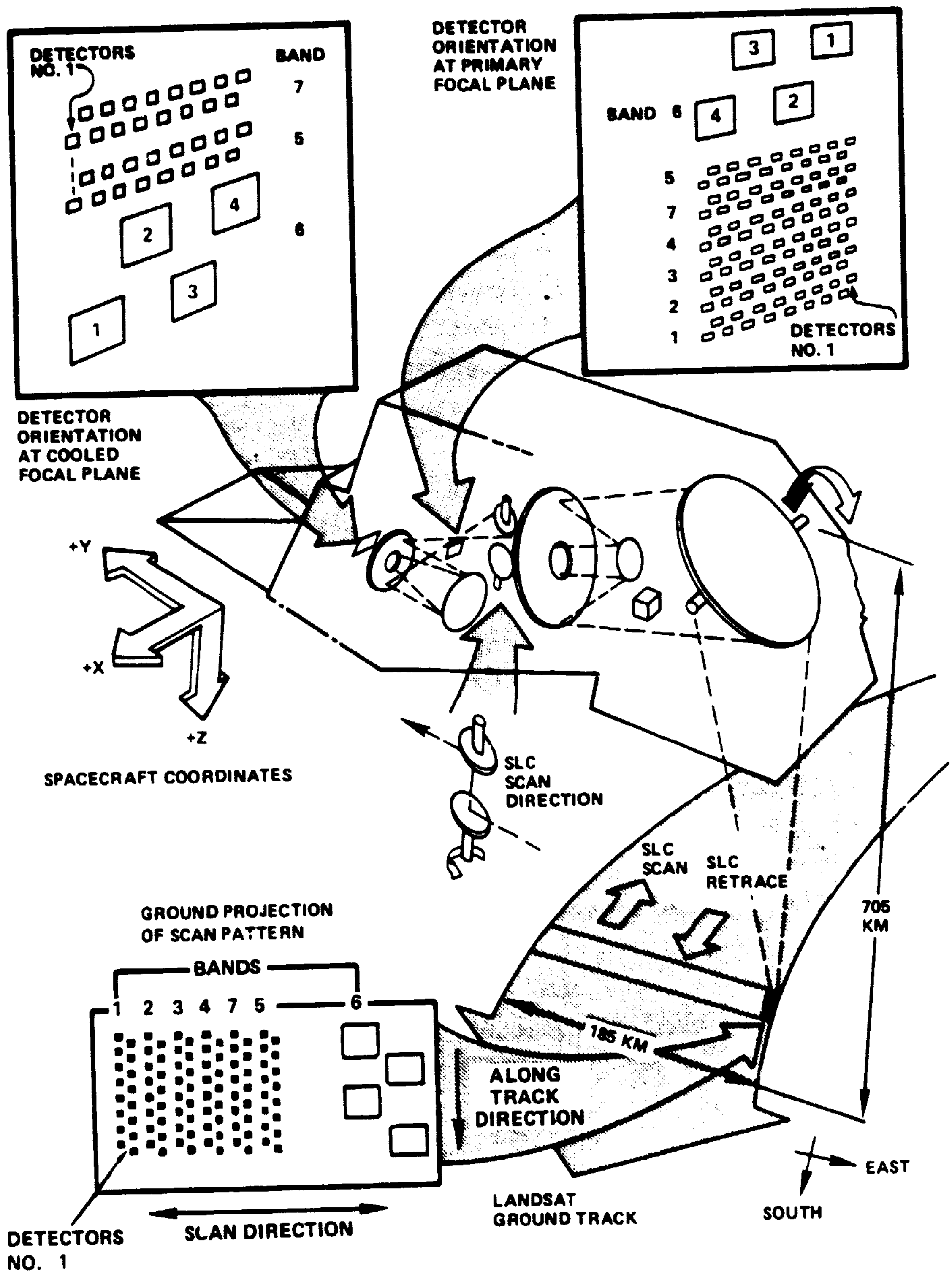

Figure 5. Detector Array Projections on Ground Track

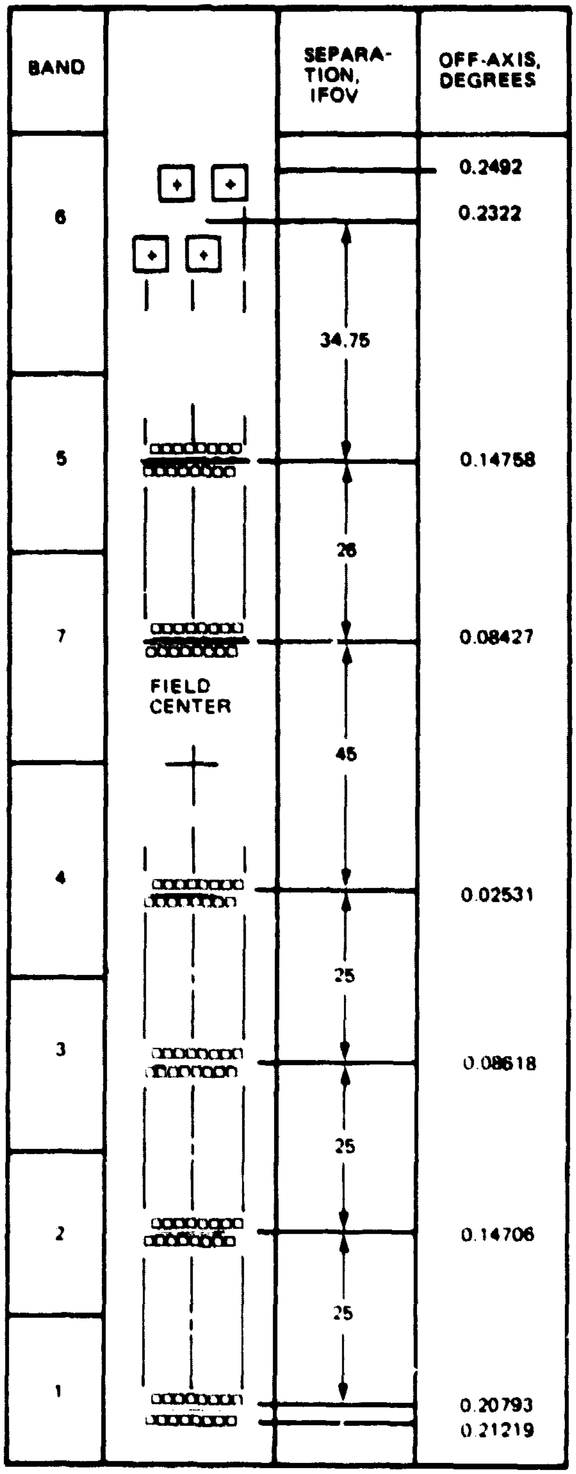

Figure 6. Detector Projection at Prime Focal Plane

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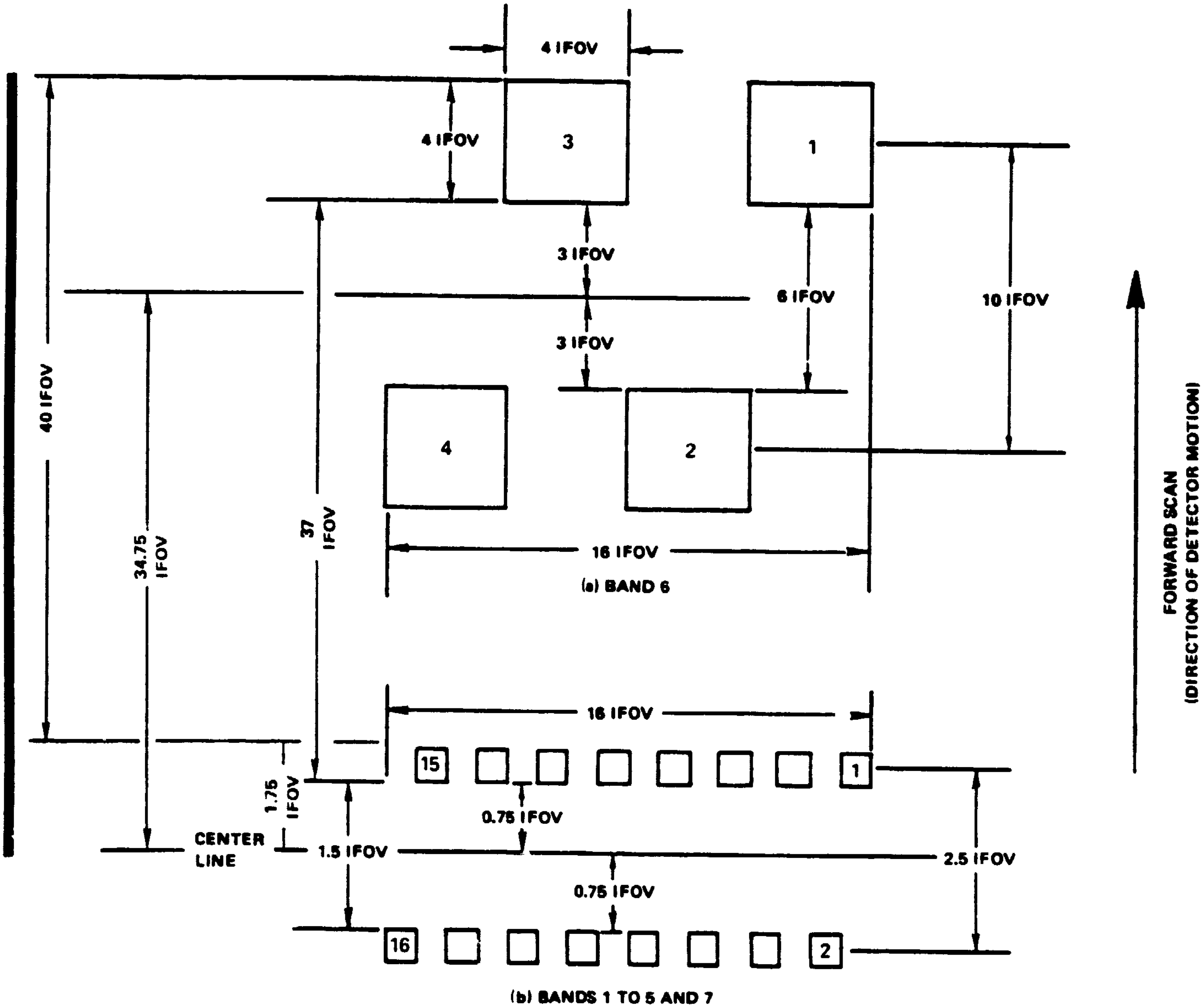

Figure 7. Details of Detector Spacing

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The odd detector values of band 5 are held at the beginning of each minor frame as are band 6 detectors 1 and 3. The Band 5 odd detectors and band 6 detector 1 samples are placed into the minor frame at which they are held. Thus, as shown in Figure 7, there are nominally 37 minor frame samples between the trailing edges of band 6 detector 1 and odd band 5 detectors on forward scans. Band 6 detector 3 samples are placed in the minor frame after the band 6 detector 1 sample. Thus, there are 36 minor frame samples between odd detectors of band 5 and band 6 detector 3.

Table 5
Detector Adjustment for Layout Geometry
and Multiplexer Sampling

Scan Direction	Minor-Frame Adjustment	
	Reverse Scan (east to west)	Forward Scan (west to east)
Band 1 even	-3	-2
Band 1 odd	0	0
Band 2 even	22	23
Band 2 odd	25	25
Band 3 even	47	48
Band 3 odd	50	50
Band 4 even	72	73
Band 4 odd	75	75
Band 7 even	117	118
Band 7 odd	120	120
Band 5 even	143	144
Band 5 odd	146	146
Band 6 1	186	183
Band 6 2	176	173
Band 6 3	187	182
Band 6 4	177	172

Note: One band-6 detector is sampled per minor frame. The sequence from line start is detector 1,3,2,4,1,3,2,4,1....

The scan mirror assembly (SMA) operates in two modes: scan angle monitor (SAM) mode and bumper mode. The bumper mode is a third backup and will not be addressed in this document. The SAM mode can operate with scan mirror electronics number 1 (SME-1) or scan mirror

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electronics number 2 (SME-2). For each SME, there exists a fifth-order polynomial describing the nominal departure from linearity (or profile) of the scan mirror forward and reverse scans. (See Appendix C.) These nominal polynomial profiles must be adjusted on the basis of first half and second half scan time data due to observed profile wander (expected to be a slowly varying adjustment of ±10 microradians at midscan over 2000 scans) and due to launch vibration profile shifts (expected to be less than ±200 microradians at midscan).

The scan mirror produces nonlinear motions normal to its scan direction. This produces cross scan or along track errors that are defined using the polynomials given in Appendix C.

- The scan mirror electronics (SME) mode is indicated in Bits 6 and 7 of TM serial Word E. Serial Word E is given in PCD TM housekeeping Word 18. See Section 5.4.7.2 (k).

- This information describes the likely changes in the supplied along scan polynomial over time. The scan profile has been observed to change as much as 10 microradians (object space) over 2000 mirror scans during prelaunch tests. Profiles have been observed to shift 50 microradians after a vibration test and the worst case in-flight nonlinearity is expected to be less than ±200 microradians.

Appendix E, TM Midscan Correction Summary, explains how a parabola is added to a smoothed profile polynomial to create a ground calibrated profile polynomial.

The scan line corrector (SLC) scans in the along-track direction and is intended to remove the along-track spacecraft and along-track Earth-rotation motion during the active scan time. The SLC position is reset by the end-scan pulse and initiates along-track scanning before the start-scan time. The SLC position at start-scan is a

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function of scan mirror turnaround time. The following SLC parameters are available at this time:

Scan frequency	13.99 Hz
Scan period	71.462 ms
Scan rate in object space	9.610 mr/sec
SLC rotation rate	576.6 mr/sec
SLC linear scan angle	35.02 mr
Linear scan amplitude in object space	583.7 μrad
Linear image displacement amplitude	0.056 in (0.142 cm)
Linear image displacement rate	0.922 in/sec (2.3 cm/sec)

5.2.2 TM Geometric Accuracy

A line synchronization signal is generated at least once each scan line. These signals relate the position of the scanning system with respect to the TM frame.

Excluding the effects of possible spacecraft attitude changes, the path of any detector on the ground will not deviate from a straight line by more than 1.0 IFOV (maximum) during the active portion of each scan. The scan profile (angular position versus time) can be described to within 0.1 IFOV (rms) by a smooth function of time with a maximum of three inflection points. A calibration profile has been derived from data taken during scan mirror subsystem operations tests and is provided in Appendix C.

The scan profiles in both along-track and cross-track directions are repeatable to the calibration profiles to within 0.1 IFOV (rms) over 400 scans and to within 0.2 IFOV (rms) over the operational lifetime of the instrument. To meet the scan profile repeatability requirements, scan profiles should be adjusted using first half scan time error and second half scan time error information that is provided in the high-data-rate stream.

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The Flight Segment (FS) includes mechanical devices that are active during the time that images are being acquired. These mechanical devices cause low-amplitude motion that is passed through the spacecraft structure and results in attitude deviations of the TM optical axis. This motion is called jitter.

Anticipated rms TM jitter error, referenced to the spacecraft coordinate system, is as follows:

Frequency Range (Hz)	Error Magnitude (arc-sec, 1 sigma)
0--0.01	36.0 All axes
0.01--0.4	10.0 All axes
0.4--7	0.30 All axes
Greater than 7	0.93 Roll 0.20 Pitch 0.30 Yaw

The above TM jitter errors result from mechanical forces interacting with spacecraft structural resonances from 0.0 to 200 Hz. Significant error is not expected to occur above 77 Hz.

Because of the developmental nature of the TM system, the NASA ground processing system is being designed to accommodate larger worst-case (peak) jitter errors of 20 arc-seconds above 7 Hz.

The amplitude and phase of jitter is expected to be asynchronous with respect to the TM scanning and thus require measurement and correction during ground processing. The TM attitude measurement capability is from 0.01 Hz to nominally 2.0 Hz, using the attitude control inertial reference units (IRU), and from nominally 2.0 to 125 Hz, using the angular displacement sensor (ADS). IRU and ADS outputs are combined on the ground to compute FS attitude deviations from nominal pointing. Below 125 Hz, the TM is structurally a rigid body, so that ADS and IRU measurements fully characterize the attitude jitter of the TM optical axis.

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5.2.3 TM Scan Rate

The scan rate (scene angular scan rate) during the usable portion of the scan will not deviate more than 1 percent (peak) from the average scan rate over any 30-second time period.

5.2.4 TM Overlap/Underlap

The peak overlap or underlap of IFOV's in adjacent scan lines of a band, not including the effect due to variations in range across the scan (i.e., bow-tie effect, altitude variation, spacecraft jitter), will be less than 0.2 IFOV error (in 395 of 400 measurements) over the full length of the scan lines when viewing the Earth. The effect of ideal orbital altitude variations on overlap/underlap of adjacent lines swept by consecutive scans must be included.

5.2.5 TM Scan-Line Length

The length of a scan line is defined as the time required for scanning between the images of two sources that are at opposite ends of the scanned field of view. The TM line length (active) will vary by no more than 1 minor frame times from the line length averaged over 400 scans, exclusive of jitter affects. Note that the specified performance (±1 minor frame) is for the active scan line length. In operation, the variation will exceed ±1 IFOV when the MSS is on simultaneously. Major frame length can vary up to 20.9 minor frames due to variation in mirror turnaround times.

5.3 TM INTERNAL CALIBRATION

The TM internal calibration system can operate in either automatic or backup mode. In the backup mode, command sequences are used to operate the three calibration lamps. An internal calibration lamp sequencer automatically sequences through the eight possible radiance levels available with the three lamps, using only one

command. Calibration data will be present in approximately 50-image-pixel locations of each scan. The TM forward scan is defined as the mirror scan from west to east during daytime operation (i.e., with the spacecraft traveling north to south). Using this as a reference, the calibration data precede the dc restore on the reverse scan and follow the dc restore on the forward scan. Dc restore is a technique for minimizing the effects of low-frequency (L/F) noise and drift. A zero-radiance level is applied to the sensors when the shutters are closed to develop a zero-clamp level for the analog-to-digital circuitry. This zero-clamp level is fractionally updated before each sweep. The zero-clamp level appears as a sensor black-level output to the ground during the shutter-closed period. Calibration data begin approximately 7.8 milliseconds after the end-of-line (EOL) pulse for the forward scan and approximately 1.0 milliseconds after the EOL pulse for the reverse scan. Each of the light calibration steps will appear in 40 consecutive scans. Note that NASA does not use calibration lamp current to determine lamp state, and that there are no plans to put these items in the PCD.

Approximately 0.5 second is required for changing calibration levels because of the time required for the lamps to warm up to full radiance (or cool down in the case of the infrared bands). For this reason, the user should not plan to use the calibration data present in the first seven scans of each 40-scan calibration level sequence. The user should examine a neighborhood of image-pixel values about the proper time and determine the location of the shoulder on the rising edge of the internal calibration curve. Look ahead 0.4 millisecond and search for the trailing edge of the shoulder of the calibration curve. Thirty contiguous pixels centered between the two shoulders can be averaged and used as a valid calibration data. Almost anytime between 2.3 and 8 milliseconds can be used for the zero-radiance-calibration level when it occurs. The dc-restore flag is black, the same as no light for bands 1 through 5 and 7. (Refer to Table 7 for the location of dc restore and blackbody data.)

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	Command*	Lamps On	Percent of Full Scale
1	All lamps OFF/Lamp C OFF	None	0
2	Lamp A ON	A	40
3	Lamp B ON	A+B	70
4	Lamp A OFF	B	30
5	Lamp C ON	B+C	50
6	Lamp A ON	A+B+C	90
7	Lamp B OFF	A+C	60
8	Lamp A OFF	C	20

The TM calibration lamp sequence is synchronous with the scans. Theoretically, it is possible to determine which of the eight calibration levels is in effect for a particular scan line. The calibration level (which lamps are on and stable) at any particular time must be derived from the data. These calibration levels are not anticipated to be exact, but no tolerances are specified. There are also no specification limits on calibration pulse rise and fall time. Actual digital values depend primarily on the internal calibration (IC) lamp configuration and the band number. Representative values can be deduced from Figures 7a and 7b. The brightest level (111), with all three IC lamps on, causes saturation at digital count 255 in band 4.

Given the preceding calibration data sequence, the user can develop the technique to locate the extract calibration data. A temperature-controlled blackbody and a temperature-measured shutter surface provide the calibration reference points for the four band-6 detectors. Band-6 dectectors view the temperature-measured shutter surface during the dc-restore calibration period and the temperature-controlled blackbody during the calibration period of each mirror scan. Refer to Table 7 for the location of these two periods in the

*There are 40 scans between each command.

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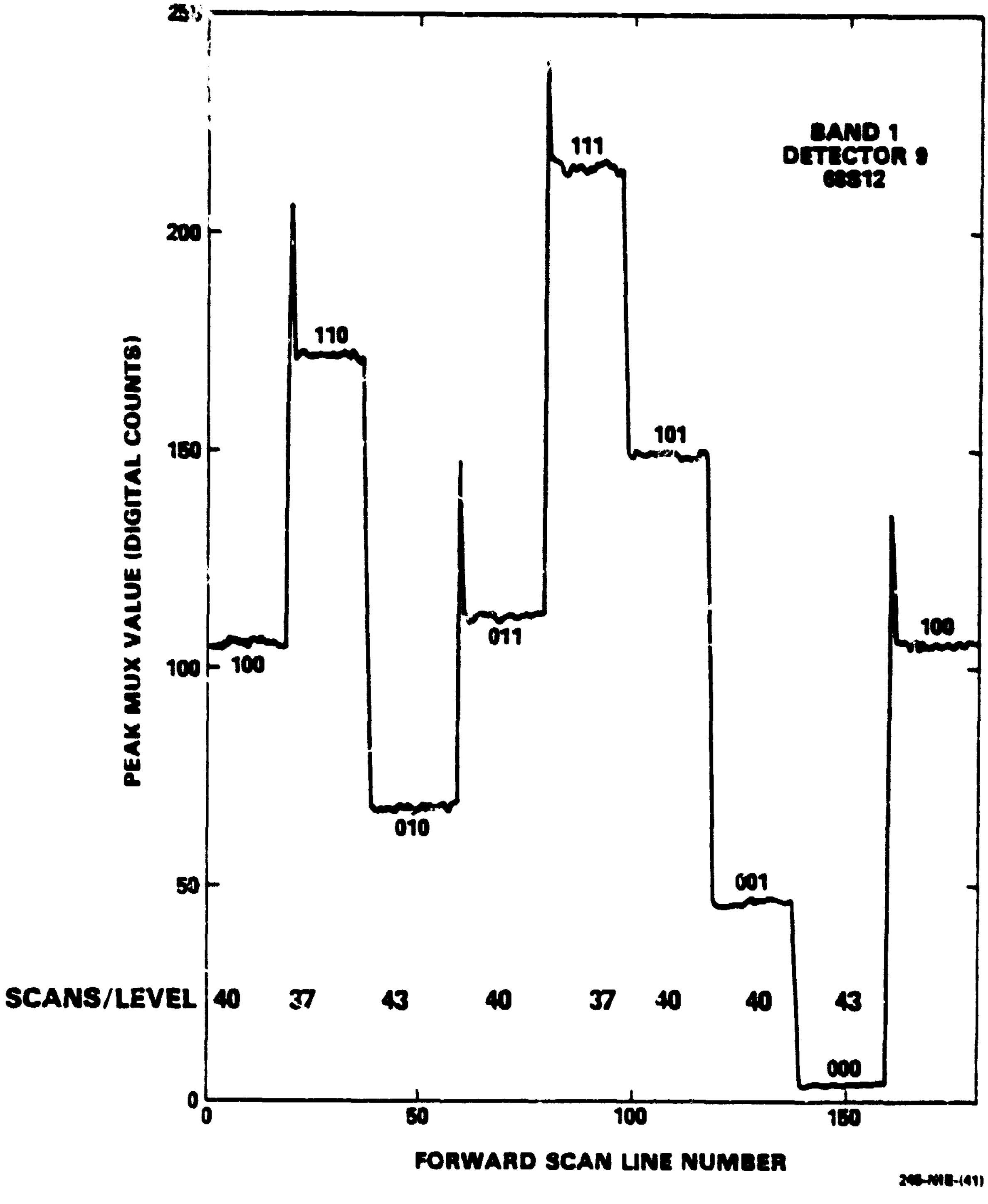

Figure 7a. TM/PF Internal Calibrator Lamp Sequence Showing Lamp Turnon Overshoot

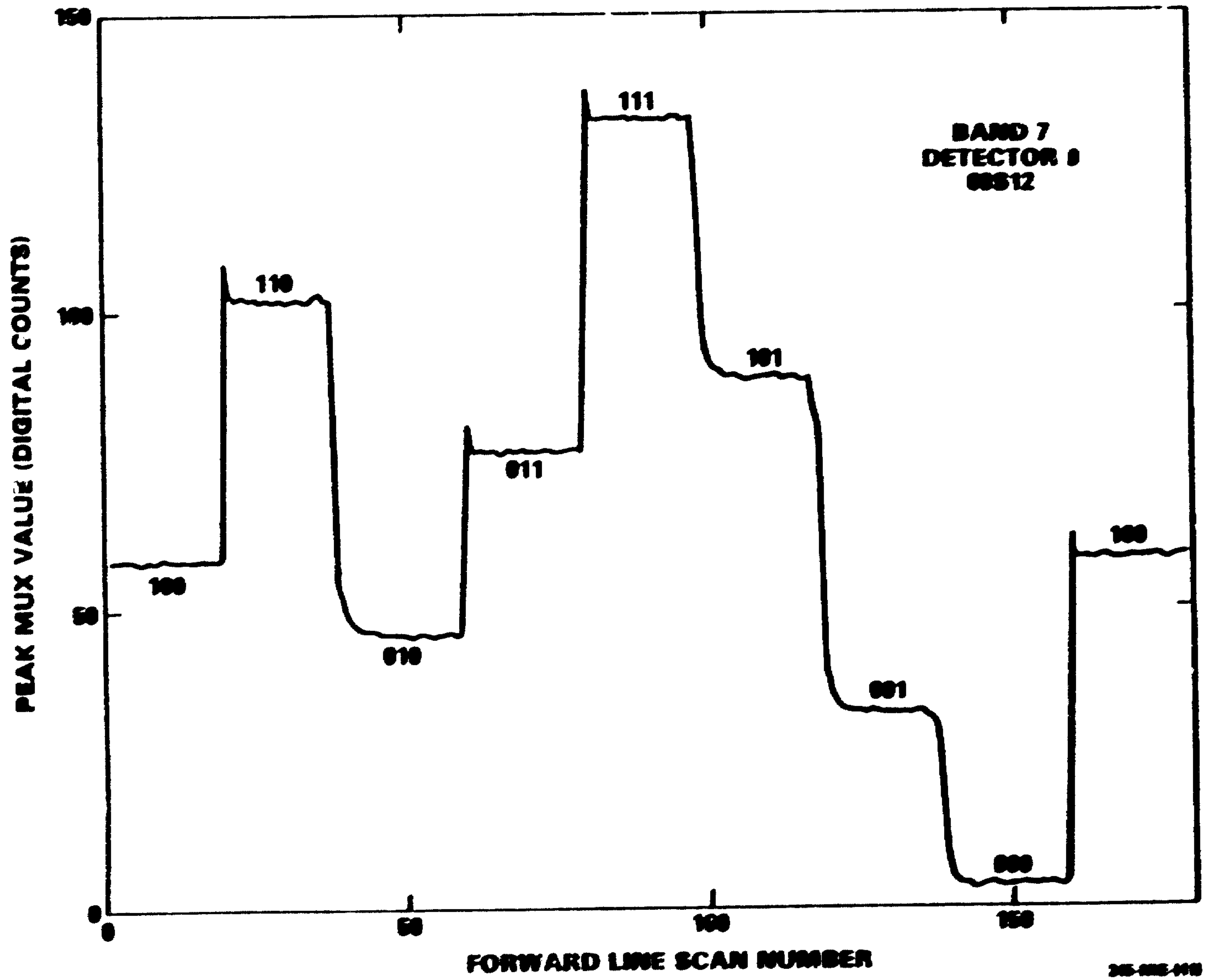

Figure 7b. TM/PF Internal Calibrator Lamp Sequence Showing Lamp Overshoot and Thermal Relaxation

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TM forward and reverse scans. The calibration shutter and blackbody temperatures are measured and inserted in mission telemetry minor-frame words 49 and 47, repectively (Table 14), and in word 3 and word 1 of the payload correction data (PCD) telemetry (reference 5.4.7.2.j). Absolute calibration will be necessary for the thermal IR channel to account for the blackbody shading factor. Compensation for temperature drift and possible emissivity variations is expected to be required throughout the mission.

5.4 TM OUTPUT FORMAT

The TM output is an 84.903 $\pm$0.080 Mbps nonreturn-to-zero mark (NRZ-M) serial bit stream. This signal employs differential transmission and has redundant outputs. Eight TM bits are grouped to form a word; words are grouped into minor frames; and minor frames are used to form major frames. Each major frame contains all data applicable to the one sweep (71.462 $\pm$0.200 milliseconds) of the scan mirror. The output format is shown in Figure 8 and is described in the following subparagraphs. The key parameters are as follows:

Swath angle: 15.390 degrees
Scan rate: 4.42191 rad/sec
Dwell time: 9.611 μsec
Line length: 6320 +0, -1 IFOV's
Filter frequency: 52.02 kHz
Data rate: 84.903 $\pm$0.080 Mbps
IFOV Bands 1 through 5 and 7 (nominal values) = 42.5 μrad;
band 6 = 170.0 μrad
Scan period: 142.925 msec
Scan frequency: 6.9967 Hz
Active scan time: 60,743 $\pm 2.9 \times 10^{-6}$ sec
Turnaround time: 10.719 msec
Overlap at 40 N: 2.30 m (bow-tie effect only)

Note that the above times are exclusive of jitter.

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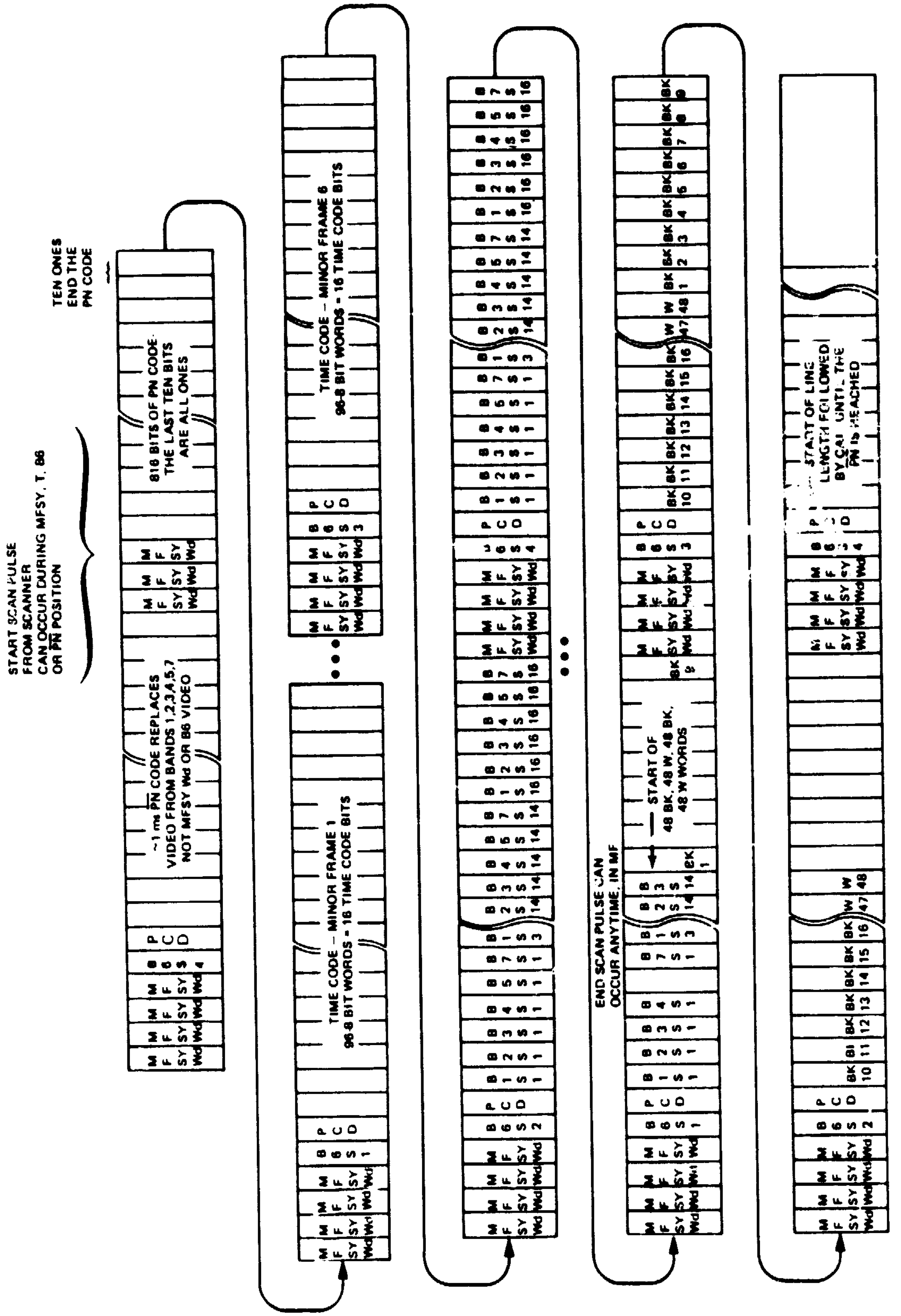

Figure 8. Thematic Mapper Data Output Format

Figure 9 details the pseudorandom noise code for the TM scan-line start.

5.4.1 Major-Frame Sync

The major-frame sync is referred to herein as the scan-line start (SLS). The SLS begins with the third word after the word in which the SLS pulse from the scanner has been sensed. The SLS consists of 816 bits of PN code generated from a 10-bit register so that the last 10 bits of the SLS are 10 logical ones. (See paragraph 5.4.5, PN Encoding.) The actual bit pattern is shown in Figure 9. The SLS pre-empts all data; however, word sync is maintained from scan to scan. The SLS words are not PN-encoded.

5.4.2 Major-Frame Format

Since each TM major frame contains the data relative to a single mirror sweep, the frame is of variable length. The major-frame length during normal operations will be 7436.5 $\pm$20.9 minor frames. Major frames are partitioned into minor frames. The major-frame formats are defined in Tables 6 and 7. (See Table 8 for the time-code format and Figure 8 for the TM data format.)

5.4.3 Minor-Frame Format

Each scan is divided into minor frames of 102 words of 8 bits each. The format for a single minor frame is shown in Figure 10. All minor frames except the last one are composed of 816 bits. The last minor frame of any major frame may contain any integral number of 8-bit words up to the full 102.

5.4.4 Minor-Frame Sync

The minor-frame sync is a 32 consecutive bit sync word. The first bit of the first minor-frame sync occurs immediately following the

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```
  1   00111101101101000000001010000010110101010001111110111
 51   10010010110000001001100100010100011011011100000111
101   1000111011111111001000001100010110111010000110101011
151   0011110010110110010000001000100100110000000101100010
201   10011101100111000101111110101000101110110101100001
251   100110110101000000111010011110100110101001001110000
301   01111100111001101111010001010101101111100001001110
351   10001110101111101101001000010000101001010110001110
401   01111111011000010001101001110010011110000110111011
451   00011000111101111101001001010000001101000110010111
501   01001011010001000101100110100101001000110000111011
551   01111000001011100101011100111011101110011001110101
601   01110111101100101000100110110001000011100101111100
651   10100110011001010101001111110011000110101111001101
701   01101001100010010111000010111101010101011111111010
751   000010101001011110001010[illegible]110111010100110111001000
801   1110000111111111
```

Figure 9. Pseudonoise Code for Thematic Mapper Scan-Line Start, Data Encoding and Complement of the Epilog

Table 6
Thematic Mapper Major-Frame Format

Nominal Number of Minor Frames Required	Starting Minor Frame	Data Type
1	0	Major-frame sync code
6	1	Time code
3153 +1, -0	7	Scene
2	**	Midscan code*
3158 +1, -0	3162 ±1	Scene
3 +0, -1	6320.2 ±0.3	End-scan code--START
	6322.2 ±0.3	End-scan code--END
2	6323 +0, -1	Line length
155 22	7280.2 ±0.3	Postamble--START
	7435.5 ±20.9	Postamble--END

816-bit SLS and is repeated every 816 bits until the next SLS re-initializes the sequence. The sync word is not PN-encoded and has been selected to maximize the opportunity to correct for bit slippages. The sync word can be interrupted by the SLS at the 8-bit word boundaries. The selected bit pattern for the sync word can be represented as the hexadecimal number 02 37 16 D1.

5.4.5 PN Encoding

All TM data except for: (1) major-frame sync, (2) minor-frame sync, and (3) postamble data are PN-encoded. Encoding is accomplished by inverting the four least significant bits (LSB's) of each 8-bit word and exclusive ORing the resultant word with a pseudorandom noise (PN) code. The PN code (Figure 9) is generated from a 10-bit seed word (0011 1101 10) by exclusive ORing the 1st and 4th bits to create the 11th bit, as shown below. The resultant 1024-bit repeating code is truncated (reset to the seed word) each minor frame so that

*If command ON, otherwise replaced with scene data.
**Approximately at center of scan.

Table 7
Thematic Mapper Data Format
(From scan line start to end of turn-around period)

Event	Forward Scan West to East at Descending Node		Reverse Scan East to West at Descending Node	
	Start Minor Frame Count	End Minor Frame Count	Start Minor Frame Count	End Minor Frame Count
End Scan	6320.2 ± 0.3	6322.1 ± 0.3	6320.2 ± 0.3	6322.2 ± 0.3
Line Length and Scan Direction	6323 +0, -1	6324 +0, -1	6323 +0, -1	6324 +0, -1
Shutter Obscuration	6933 ± 50	7808 ± 50	6445 ± 50	7320 ± 50
DC Restore	7378 ± 50	7703 ± 50	6870 ± 50	7195 ± 50
Calibration	7058 ± 50	7118 ± 50	6550 ± 50	6610 ± 50
$\overline{PN}$	7280.2 ± 0.3	7435.5 ± 20.9	7280.2 ± 0.3	7435.5 ± 20.9

Note: The start and end times are nominal times.

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Table 8
Thematic Mapper Time-Code Format

	A	B	C	D	E	F
1	0	0	0	0	0	0
2	0	10 D(8)	10 D(4)	10 D(2)	10 D(1)	0
3	0	10 H(8)	10 H(4)	10 H(2)	10 H(1)	0
4	0	10 M(8)	10 M(4)	10 M(2)	10 M(1)	0
5	0	10 s(8)	10 s(4)	10 s(2)	10 s(1)	0
6	0	100 ms(8)	100 ms(4)	100 ms(2)	100 ms(1)	0
7	0	1 ms(8)	1 ms(4)	1 ms(4)	1 ms(1)	0
8	0	X1	X2	X3	X4	0
9	1	100 D(8)	100 D(4)	100 D(2)	100 D(1)	0
10	1	1 D(8)	1 D(4)	1 D(2)	1 D(1)	0
11	1	1 H(8)	1 H(4)	1 H(2)	1 H(1)	0
12	1	1 M(8)	1 M(4)	1 M (2)	1 M(1)	0
13	1	1 s(8)	1 s(4)	1 s(2)	1 s(1)	0
14	1	10 ms(8)	10 ms(4)	10 ms(2)	10 ms(1)	0
15	1	1/2 ms	1/4 ms	1/8 ms	1/16 ms	0
16	1	*	*	*	*	0
Output Sequence: A1-A16, B1-B16, C1-C16, D1-D16, E1-E16, F1-F16						

D - Day
H - Hours
M - Minutes
s - Seconds
ms - Milliseconds

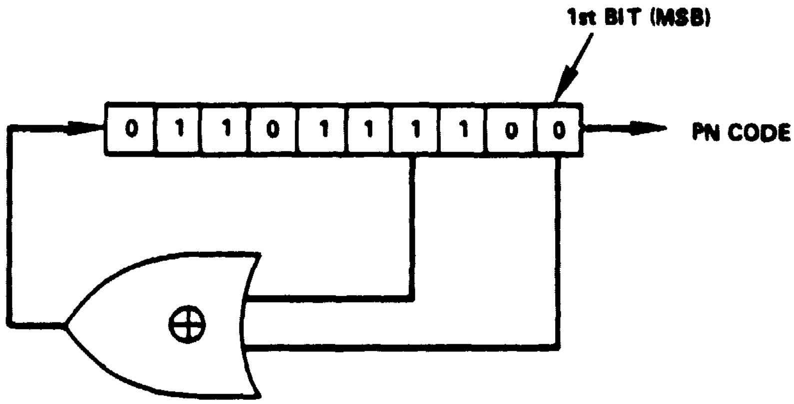
* = Spares (set to "1")
( ) = BCD weight
X(1-4) = spacecraft ID as follows:
1110 = Landsat-D
1101 = Landsat-D'

SYNC	SYNC	SYNC	SYNC	BAND 6	PCD
B1 S1	B2 S1	B3 S1	B4 S1	B5 S1	B7 S1
B1 S3	B2 S3	B3 S3	B4 S3	B5 S3	B7 S3
B1 S5	B2 S5	B3 S5	B4 S5	B5 S5	B7 S5
B1 S7	B2 S7	B3 S7	B4 S7	B5 S7	B7 S7
B1 S9	B2 S9	B3 S9	B4 S9	B5 S9	B7 S9
B1 S11	B2 S11	B3 S11	B4 S11	B5 S11	B7 S11
B1 S13	B2 S13	B3 S13	B4 S13	B5 S13	B7 S13
B1 S15	B2 S15	B3 S15	B4 S15	B5 S15	B7 S15
B1 S2	B2 S2	B3 S2	B4 S2	B5 S2	B7 S2
B1 S4	B2 S4	B3 S4	B4 S4	B5 S4	B7 S4
B1 S6	B2 S6	B3 S6	B4 S6	B5 S6	B7 S6
B1 S8	B2 S8	B3 S8	B4 S8	B5 S8	B7 S8
B1 S10	B2 S10	B3 S10	B4 S10	B5 S10	B7 S10
B1 S12	B2 S12	B3 S12	B4 S12	B5 S12	B7 S12
B1 S14	B2 S14	B3 S14	B4 S14	B5 S14	B7 S14
B1 S16	B2 S16	B3 S16	B4 S16	B5 S16	B7 S16

B = BAND NUMBER S = SENSOR NUMBER

Figure 10. TM Minor-Frame Format

the last 10 bits of the code used in each minor frame are "1's." Note that, since the first four words (32 bits) of each minor frame are minor-frame sync and not encoded, the first bit used in encoding is the 33rd bit of the sequence produced by the generator shown. The generator also produces the PN code used for major-frame sync and the inverted PN code used as postamble.



The PN code generator shown above is reset to a fixed value (00 1111 0110) for the start of scan line and for the start of each minor frame thereafter. This starting code, along with all other codes produced by the PN code generator, are shown in Figure 9. Note that the first 32 bits of each minor frame are not PN-encoded. (See Figure 10.) PN encoding is performed only on bits 33 through 816 of each minor frame. The PN code bits (Figure 9) are exclusive ORed with corresponding video data word bits (the last 4 bits of each video word are inverted before the exclusive OR process is performed). The PN-encoded data are transmitted to ground, most significant bit (MSB) first. The PN inverse code consists of four words of minor-frame sync, band 6 sensor word, and PCD word followed by 768 bits of inverted PN code (PN bits 49 to 816 inverted) repeated

continuously for approximately 1 millisecond. Refer to Table 8 for the timing of PN encoding.

5.4.6 Band 6 Sensor Word

The outputs of the four thermal-band detectors of band 6 appear in sequential minor frames as the first 8 bits immediately following the minor-frame sync. The signal from detector 1 of band 6 occurs in the first minor frame after SLS and every fourth minor frame thereafter. The output sequence is detector 1, detector 3, detector 2, then detector 4. Band 6 sensor words are PN-encoded.

5.4.7 Payload Correction Data

The PCD contain only data required by ground stations for correcting TM sensor data. The data sources, data, and timing associated with their collection, formatting, and transmission to ground stations are provided in this section for the TM payload data stream. The PCD are transmitted to ground stations by a 32-kbps digital signal modulated on the S-band carrier and within the TM payload data stream, carrying the following types of data:

- Angular Displacement Sensor (from the Angular Displacement Sensor Assembly-ADSA)
- ADS Temperature (from ADSA)
- Gyro Data (from OBC)
- Gyro Drift Data (from OBC)
- Attitude Estimate (from OBC)
- Ephemeris (from OBC)
- TM Housekeeping Data (from OBC)
- Spare Housekeeping Data (from OBC)
- S/C Time Code (from the Power Distribution Unit-PDU)
- MUX Status (generated in the MUX)
- A/D Ground Reference (from ADSA)
- Sync (generated in the MUX)

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- Major Frame Identification - MFID (generated in the MUX)
- Telemetry Frame Correlation (generated in the MUX)

The PCD contain information from many sources, including a 2- to 125-Hz bandwidth jitter measuring sensor. The jitter information is derived from a three-axis angular displacement sensor (ADS) that is mounted on or near the TM instrument. Plans include an initial calibration of this sensor based on prelaunch test results. The ADS output will be quantized to a 12-bit digital output including sign per axis. The PCD are formatted, subsequently multiplexed onto a 32-kbps digital S-band data link, and inserted in the TM payload data stream.

The sixth word in each TM minor frame contains either 8 bits of PCD or, in every sixteenth minor-frame, a minor-frame counter number. The minor-frame count commences with a count of "zero" at minor-frame 16 (the 16th minor frame of video after SLS) and is incremented by one and inserted every 16 minor frames thereafter. The PCD "word" is either SYNC, FILLER, or DATA. (See paragraph 5.4.7.1.) The words are output in the order FILLER, SYNC, DATA, DATA, DATA, FILLER, FILLER, FILLER.... SYNC words are hexidecimal 16's (00010110) and FILLER words are hexidecimal 32's (00110010). DATA words are repeated twice (three words total) and represent eight unique bits of PCD. Approximately 22-filler words are required between each data set. PCD and minor-frame counter words are PN-encoded, and the left-most bit of MSB is output first. PCD word sync will be repeated in the unpacked PCD format every 26 ± 1 words.

5.4.7.1 Packed and Unpacked PCD Formats--The PCD, which are asynchronous with TM data, are generated at 4 Kbytes/sec. The TM requests a PCD word every minor frame or at a rate of 97,545 Hz. As a result, the PCD transmitted in word 6 of the wideband TM payload data stream are in an unpacked format. Filler words are used to rate buffer the PCD 4 Kbytes/sec generation rate up to the 97,545 Hz TM PCD word request rate. The number of filler words required to

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accomplish this rate buffering will vary. The user will be required to synchronize on the unpacked format data stream, extract the data words, perform a majority vote on the validity of the three identical data words to select one of the three words, and pack the selected data words into a buffer. The unpacked PCD format (TM minor-frame word 6) must be reformatted to match the packed PCD format by the user before the data can be extracted. (See Figures 11 and 12 for the PCD major- and minor-frame formats.)

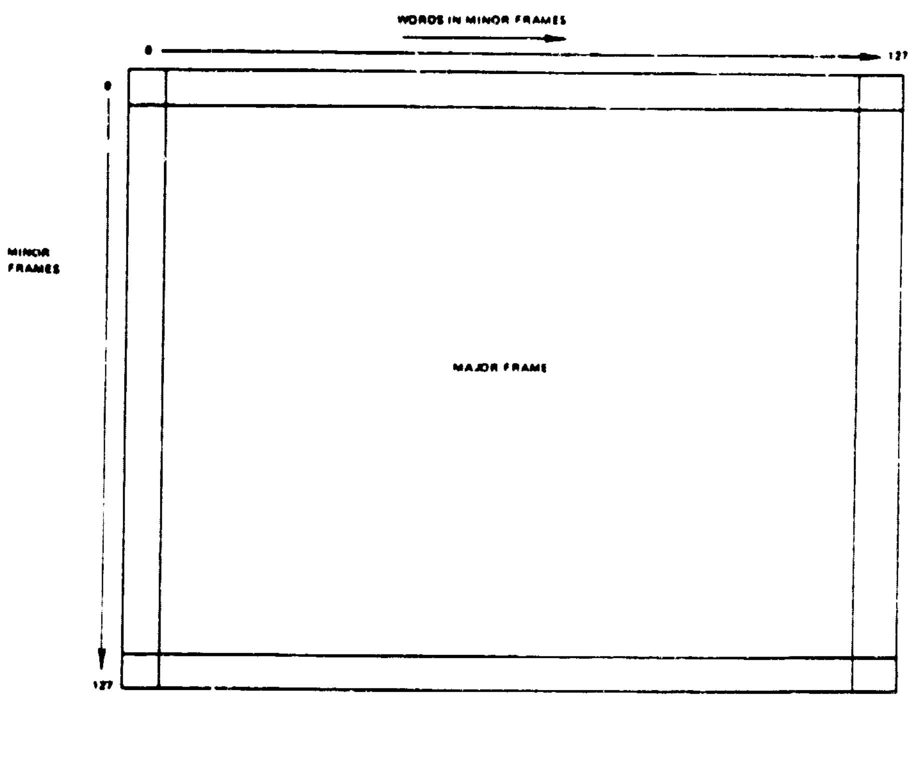

Figure 11. PCD Major-Frame Format

32 ms — WORDS IN MINOR FRAME

SYNC		0,1,2
ADS	1*	3,4
ADS	2	5,6
ADS	3	7,8
		9
		10
ADS	1	11,12
ADS	2	13,14
ADS	3	15,16
GYRO (FIG 15)		17
		18
ADS	1	19,20
ADS	2	21,22
ADS	3	23,24
		25,26
ADS	1	27,28
ADS	2	29,30
ADS	3	31,32
GYRO (FIG 15)		33
		34
ADS	1	35,36
ADS	2	37,38
ADS	3	39,40
		41,42
ADS	1	43,44
ADS	2	45,46
ADS	3	47,48
GYRO (FIG 15)		49
		50
ADS	1	51,52
ADS	2	53,54
ADS	3	55,56
		57,58
ADS	1	59,60
ADS	2	61,62
ADS	3	63,64

WORDS IN MINOR FRAME

MFID		65
ADS	1	66,67
ADS	2	68,69
ADS	3	70,71
SUB COMM (FIG 13)		72
		73
ADS	1	74,75
ADS	2	76,77
ADS	3	78,79
		80
GYRO (FIG 15)		81
ADS	1	82,83
ADS	2	84,85
ADS	3	86,87
		88,89
ADS	1	90,91
ADS	2	92,93
ADS	3	94,95
		96
GYRO (FIG 15)		97
ADS	1	98,99
ADS	2	100,101
ADS	3	102,103
		104,105
ADS	1	106,107
ADS	2	108,109
ADS	3	110,111
		112
GYRO (FIG 15)		113
ADS	1	114,115
ADS	2	116,117
ADS	3	118,119
		120,121
ADS	1	122,123
ADS	2	124,125
ADS	3	126,127

* 1 = roll (x), 2 = pitch (y) and 3 = yaw (z)

Figure 12. PCD Minor-Frame Format

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a. Unpacked PCD format (TM minor-frame word 6)

TM Payload Word 6 (PCD word content)	Value
FILLER	HEX 32 (00110010)
SYNC	HEX 16 (00010110)
DATA	
DATA — one 8-bit data value repeated twice	
DATA	
FILLER	HEX 32
FILLER	HEX 32
FILLER	HEX 32
. . .	

It should be noted that PCD are replaced in minor frames 16, 32, 48 ... by minor frame ID words.

b. Packed PCD format (by user)

Subcom sequence length: 4 major frames
Major-frame length: 128 minor frames
Minor-frame length: 128 words, 8 bits word (Figure 12)

(1) PCD major-frame format (Figure 11)
Sync word hexidecimal FAF320

(2) PCD subcom (Figure 13 and Figure 14)

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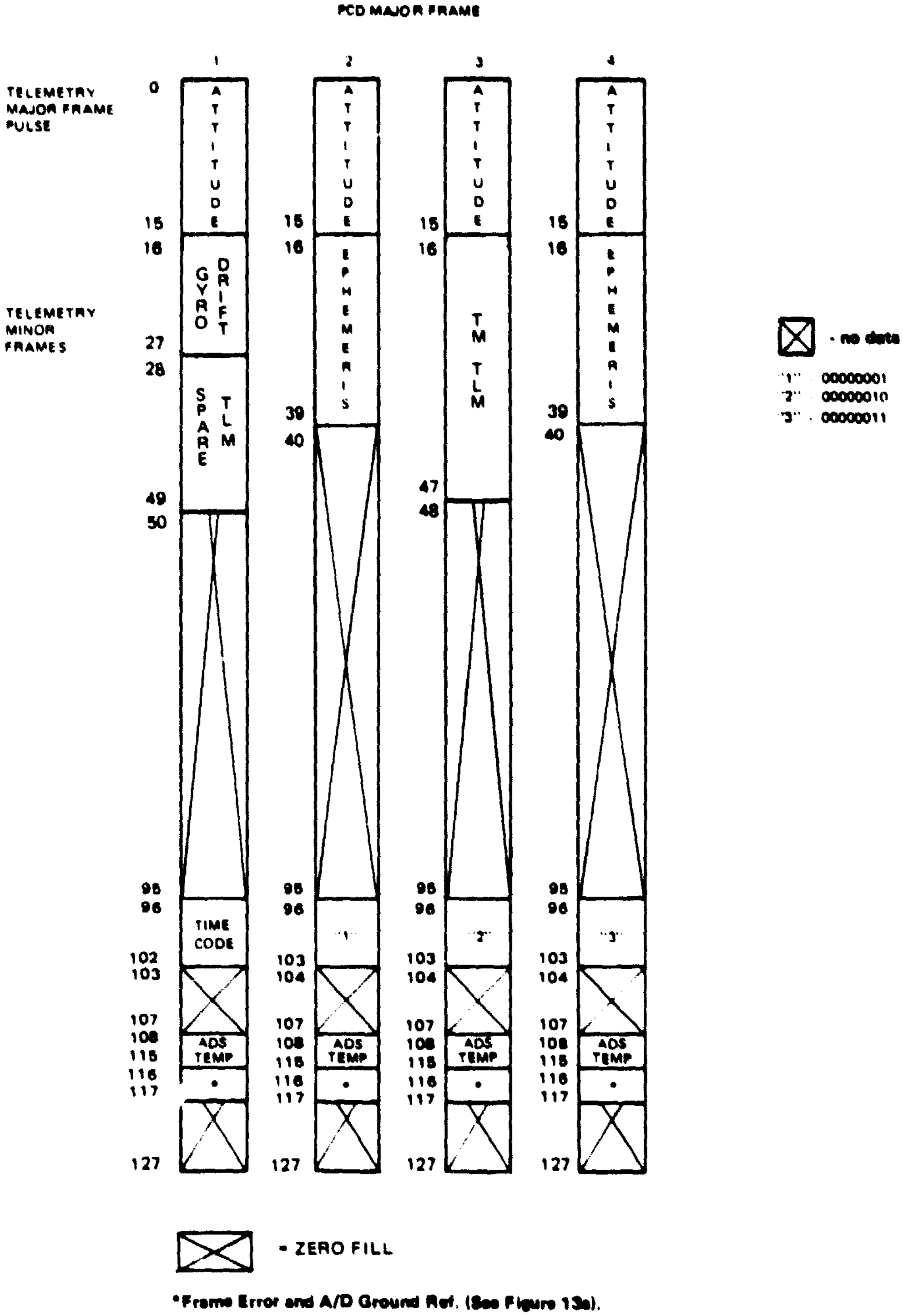

Figure 13. Subcommutation Data (Word 72)

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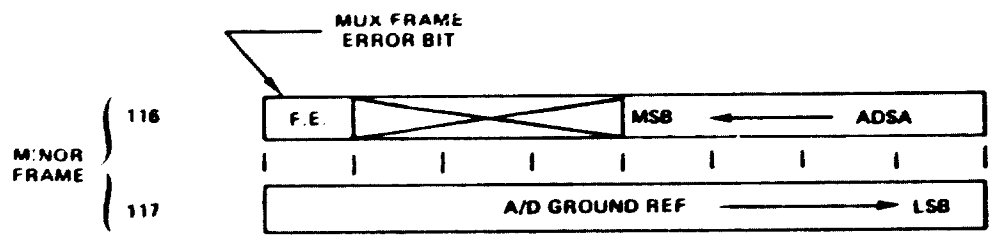

Figure 13a. Frame Error & A/D Ground Reference

Contents of Word 65	MSB							LSB
1st Minor Frame	X	0	0	0	0	0	0	0
2nd Minor Frame	X	0	0	0	0	0	0	1
3rd Minor Frame	X	0	0	0	0	0	1	0
63rd Minor Frame	X	0	1	1	1	1	1	1
127th Minor Frame (END-OF-MAJOR FRAME n)	X	1	1	1	1	1	1	1

Figure 14. Frame-Counter Identification Bit Pattern

5.4.7.2 Data and Timing

a. ADS--Each axis of the ADS will be sampled every 2 milliseconds (eight words). The sample will be converted to a 12-bit integer word (including sign) and inserted in two consecutive words of the format, with the four MSB's of the first word set to zero. The data will be sampled during the odd-numbered word time preceding the first of the two data

words. For example, ADS axis 1 will be sampled during the following word times of each minor frame of PCD:

1	33	65	97
9	41	73	105
17	49	81	113
25	57	89	121

The three-axis ADS sensor output units are in microradians. The full-scale output of the three ADS outputs are calibrated to be 250 microradians for the roll, pitch, and yaw axes. The relative alignment between the ADS and the spacecraft is $X_{ADS} = X_{S/C}$ where Y_{ADS} and Z_{ADS} are rotated CCW nominally 20° about x. The LSB weight is $250/2^{11}$. The accuracy of ADS data (analog-to-digital converter resolution) is 0.025 arc-seconds. No attempt to calibrate the ADS post launch is planned. Predicted jitter levels indicate the need for all ADS data. If this analysis proves to be too conservative, less use of ADS data may be possible in routine processing. NASA has designed its processing to use all ADS data.

b. ADS Temperature--Up to four ADS-related temperatures will be sampled once a PCD major frame (4.096 sec). Each sample will be converted into two 8-bit words with the first 4 bits of the first word set to zero. As before, the data will be sampled in the word time preceding the first data word. That is:

	Minor Frame	Data Word	Sample Time (word)
Temperature 1	108-109	72	71 (108)
Temperature 2	110-111	72	71 (110)
Temperature 3	112-113	72	71 (112)
Temperature 4	114-115	72	71 (114)

ADS temperature is in degrees centigrade with an LSB weight of 0.1758 C.

Temperature compensation of ADS and DRIRU data does not appear to be necessary and is not planned at this time.

c. Gyro Data--Each axis of both dry rotor inertial reference units (DRIRU's) is sampled by the OBC every 64 milliseconds. The data will consist of a 24-bit word for each axis (a total of 72 bits). The data, timing of the data sampling, transfer, and readout in the PCD format are shown in Figure 15 and Figure 16. Each 1-millisecond data sampling period is initiated by that 16-milliseconds interrupt to the OBC which occurs 36 milliseconds after the start of an even-numbered PCD minor frame (i.e., 4 milliseconds after the start of each odd-numbered PCD minor frame). Since the start of every fourth PCD minor frame numbered "0" is coincident with the start of the telemetry major frame and time is contained in that PCD major frame (Figures 12 and 13), the time of the start of each gyro data sampling period can be fixed.

Minor Frame	Word in Minor Frame											
		17		33		49		81		97		113
0		⊠		⊠		⊠		1_1		1_2		2_1
1		1_3		2_2		2_3		3_1		3_2		3_3
2		⊠		⊠		⊠		1_1		1_2		2_1
3		1_3		2_2		2_3		3_1		3_2		3_3
⋮		⋮		⋮		⋮		⋮		⋮		⋮

⊠ = No Data

1_n - X Axis
2_n - Y Axis
3_n - Z Axis

Three to eight bit bytes are required per axis: the MSB is output first

Figure 15. Gyro Data

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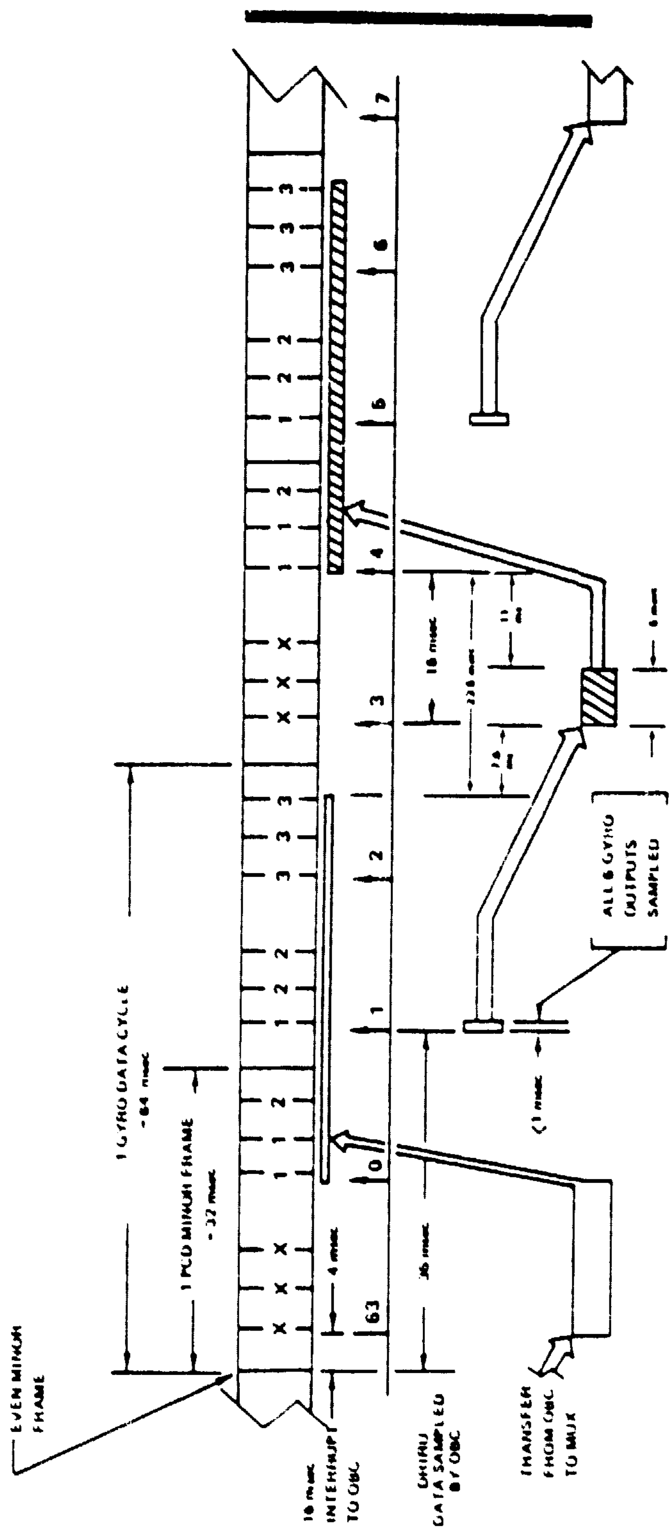


Figure 16. Gyro Data Timing

Gyro output units are arc-seconds of angle to an accuracy of 0.05 arc-seconds (analog-to-digital converter resolution). Each of the gyro three-axis outputs are 23 bits plus sign 2's complement binary. The gyro LSB in the standard operating mode (low rate mode) is 0.05 arc seconds. The relationship between the sampling period, transfer, and readout is also fixed. (See Figure 16.) That is, with reference to Figure 12, the data present in:

Word	Minor Frame	Axis
81 and 97	2	X
17	3	X
113	2	Y
33 and 49	3	Y
81, 97 and 113	3	Z

were sampled by the OBC in the period starting at word 16 of minor frame 1. The data are output in the next PCD minor frame.

d. Gyro Drift Data--The drift calculation is performed by the OBC approximately once a minute. Gyro drift parameters are updated asynchronously based on star sightings. The data consist of 31 bits and sign for three axes (THETBX, THETBY, THETBZ). The data will be transferred to the formatter during the fourth transfer period (Figure 17), between the attitude data and the telemetry spares data.

In the normal operating mode, the OBC computed attitude, filtered to 1/2 Hz bandwidth, is output to provide a low frequency reference attitude. The 4.096-second sample frequency does not support reconstruction of this signal unless the frequency content turns out to be much lower than the filter allows. Gyro data are provided every 64 ms to

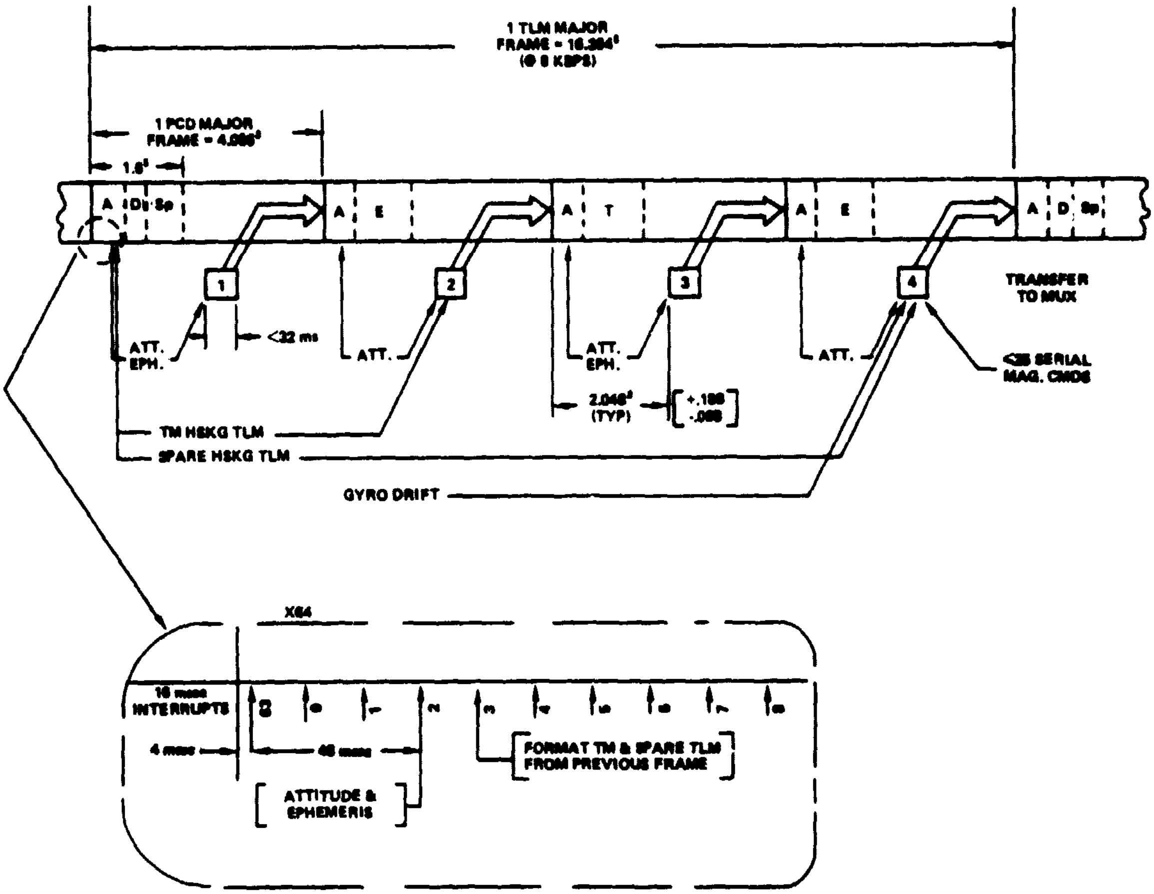


Figure 17. Subcommutation Data Timing

contain 0-2 Hz frequency data and the ADS data, provided every 2 ms, contain frequencies up to 125 Hz. Since these sensors have different frequency responses, the data must be appropriately compensated to be combined.

Gyro drift is calculated on board and must be subtracted from the gyro data as a correction to calculate spacecraft attitude. The units of gyro drift rate are radians/512 ms. Gyro drift output data (in units of radians/512 ms) are calibrated at an LSB weight of 9.6×10^{-5}.

The format and frame position of the gyro drift binary scaled integer data is as follows:

MSB 2^{-17} LSB 2^{-47} (SCALE 16)

		SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX
MINOR FRAME	THETA BX	16	17	18	19
	THETA BY	20	21	22	23
	THETA BZ	24	25	26	

The data will appear in word 72 of minor frames 16 through 27 of the PCD major frame that starts at the telemetry major-frame pulse. (See Figure 13.) Since the data will be sampled every 16.384 seconds, it will repeat four times between each calculation.

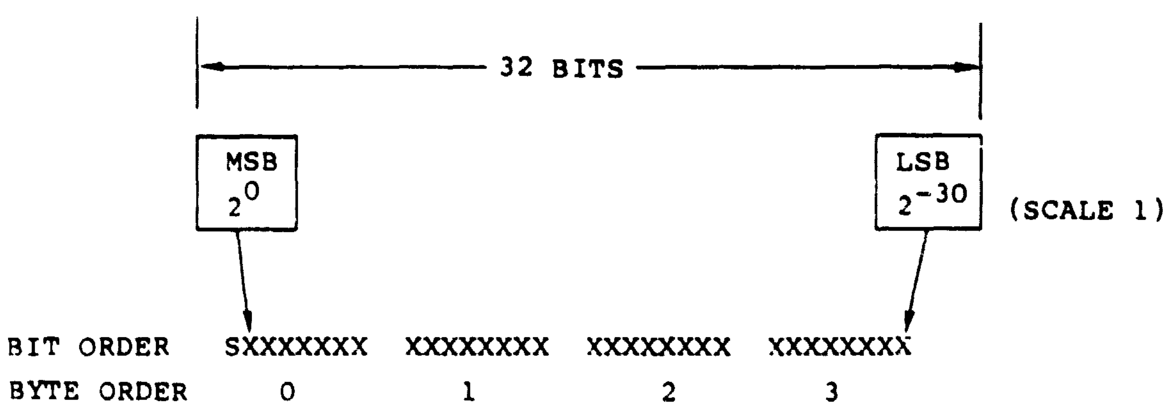
e. Attitude--The OBC calculates a flight segment attitude estimate every 512 milliseconds. The OBC will output one of eight sets of data in telemetry, starting with the one calculated 52 milliseconds after the telemetry major-frame pulse and every 4.096 seconds thereafter (once a PCD major frame). Attitude is Euler parameters (i.e., EPA1, EPA2, EPA3, EPA4--Table 17) that specify vehicle attitude relative to Earth-centered inertial frame (nondimensional). $EPA_{1,2,3,4}$ are components of the references quaternion (as propagated from gyro data) which defines spacecraft attitude. Components 1

through 3 define the Eigen axis of rotation in ECI coordinates, and component 4 defines rotation about that axis, as follows:

$$\left.\begin{aligned} EPA_1 &= A_x \sin\left(\frac{\theta}{2}\right) \\ EPA_2 &= A_y \sin\left(\frac{\theta}{2}\right) \\ EPA_3 &= A_z \sin\left(\frac{\theta}{2}\right) \end{aligned}\right\} \begin{aligned} A &= \text{Eigen axis of rotation} \\ \\ \theta &= \text{magnitude of rotation} \end{aligned}$$

$$EPA_4 = \cos\left(\frac{\theta}{2}\right)$$

Euler double precision words (36 bits) are compressed and Scaled to 32 bit, 2's complement binary form as follows:



The four compressed Euler Parameters (EP) are output in word 72 of minor frames 0 through 15 of each PCD major frame. (See Figure 13.) The output sequence of EPA1 through EPA4 is as follows:

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Content	PCD Minor Frame Numbers			
EPA1	0	1	2	3
EPA2	4	5	6	7
EPA3	8	9	10	11
EPA4	12	13	14	15
BYTE ORDER	1	2	3	4

The time associated with attitude data contained within the PCD can be derived from the time code contained in words 96 through 102 of PCD major frame 1. The derivation is as follows:

PCD Major-Frame Number	Time Computation
1	time code - 4.096 seconds + 36 milliseconds
2	time code + 36 milliseconds
3	time code + 4.096 seconds + 36 milliseconds
4	time code + 8.192 seconds + 36 milliseconds

Euler parameter data provide information that are redundant to the gyro data described in c above. Attitude accuracy is expected to be 0.25 arc-seconds or 3 percent, whichever is greater, after filtering/smoothing. Full scale (zero-to-peak) jitter may be up to 36 arc seconds (1 sigma).

The OBC calculates an attitude estimate (Euler parameters) every 512 ms and places 1 out of 8 of these in PCD starting with the one calculated 52 ms after the telemetry major frame pulse. This attitude estimate is based on the sampling of gyro data that occurred 36 ms following the major frame pulse. Ephemeris is calculated for the same epoch as attitude, but only 1 out of 16 sets is placed in PCD.

f. Ephemeris--This calculation is made by the OBC when the attitude calculation is made. In this case, only 1 of 16 data sets will be output in the PCD (i.e., every other PCD major frame - 8.192 seconds).

Ephemeris consists of spacecraft position components (EOGBRF, Table 23) X, Y, and Z in meters and spacecraft velocity components (EOGBVF, Table 23) X, Y, and Z in meters per millisecond. Ephemeris is output as 32-bit binary words defining $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ in Earth-centered imertial true-of-date (ECITOD) coordinates. In the ECITOD coordinate system, the Z-axis is along a line from the center of the Earth coincident with the true Earth spin axis, positive north. The X-axis is along a line from the center of the Earth toward the intersection of the true Equator and true ecliptic of date. The Y-axis completes the right-handed set. (The ECITOD system varies slowly with respect to a truly inertial system due to precession and nutation of the Earth's axis and precession of the plane of the ecliptic. These variations occur slowly enough that the ECITOD system can be considered to be inertial over a span of a few days for attitude control purposes.)

The ephemeris data are 36-bit double precision words that have been compressed to 32-bit, 2's complement form by dropping the second sign bit and the three LSB's. The scale factor is 23 for position and 3 for velocity. The format of these data is as follows:

Position Components

WORD 72	MSB 2^{22}			LSB 2^{-8}	
	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	SCALE = 23
X	16	17	18	19	
Y	20	21	22	23	MINOR FRAME
Z	24	25	26	27	

Velocity Components

WORD 72	MSB 2^{2}			LSB 2^{-28}	
	SXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX	SCALE = 3
X	28	29	30	31	MINOR FRAME
Y	32	33	34	35	MINOR FRAME
Z	36	37	38	39	MINOR FRAME

The data will appear in word 72 of minor frames 16 through 39 of every other PCD major frame. (See Figure 13.) These major frames will carry the "1" and "3" identifier in place of time code.

The time associated with ephemeris data contained within the PCD can be derived from the time code contained in words 96 through 102 of PCD major frame 1. The derivation is as follows:

PCD Major-Frame Number	Time Computation
1	time code - 4.096 seconds + 36 milliseconds
2	time code + 36 milliseconds
3	time code + 4.096 seconds + 36 milliseconds
4	time code + 8.192 seconds + 36 milliseconds

g. Fifty-six bits of spacecraft time code (seven 8-bit words) are inserted in the PCD stream. This code represents the start time for PCD major frame 0. The 56 bits of spacecraft time code are subcommutated into word 72 of minor frames 96 through 102 of the first PCD major frame following the telemetry major-frame pulse. (See Figure 13.) The output sequence for the 56 time-code bits is contained in Table 9.

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Table 9
Time Code Format in Payload Correction Data
(word 72 of minor frames 96 through 102 of PCD major frame 0)

Minor-Frame Number	Words 72 Bits 0-7	Content of Word 72 (PCD major-frame 0)
96	0-3 4-7	Spacecraft ID Hundreds of days
97	0-3 4-7	Tens of days Units of days
98	0-3 4-7	Tens of hours Units of hours
99	0-3 4-7	Tens of minutes Units of minutes
100	0-3 4-7	Tens of seconds Units of seconds
101	0-3 4-7	Hundreds of milliseconds Tens of milliseconds
102	0-3 4-7	Units of milliseconds Fractions of milliseconds (LSB=1/16 millisecond)

Notes: Bits 0-7 = Two BCD words in format (MSB-LSB), (MSB-LSB).
Spacecraft ID are encoded as follows:
1110 = Landsat-D
1101 = Landsat-D'

The data consist of the 56 bits (i.e., 4 bits of spacecraft ID, 52 time-code bits) that determine the time when the telemetry major-frame pulse occurred. The data will appear in word 72 of minor frame 96 through 102 of the first PCD major frame after the telemetry major-frame pulse (Figure 13.)

h. PCD Minor-Frame Sync--The same sync pattern used for the telemetry data will appear in words 0 through 2 of each PCD minor frame.

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i. Minor-Frame Identification (MFID)--A 0 to 127 count of minor frames will appear in word 65 of each PCD minor frame.

j. Major Telemetry Frame Identification--Word 72 of minor frames 96 through 103 of the second, third, and fourth PCD major frames of a four-frame set (Figure 13) will contain a unique identifier (1, 2, or 3).

k. TM Housekeeping Telemetry--A total of 248 bits of TM housekeeping telemetry data may be stripped out of the telemetry format by the OBC and sent to the formatter. The data will be collected at the fifth 16-milliseconds interrupt after the start of a telemetry major frame and transferred to the formatter following the attitude data in transfer period 2. (See Figure 17.)

The data will appear in word 72 of minor frames 16 through 46 of the third PCD major frame after the telemetry major-frame pulse. (See Figure 13.) This major frame will carry the identifier "2" in place of time code. The data will be from the previous telemetry major frame. The TM telemetry will consist of the following:

Word 72 of Minor-Frame Number	Description
16	Blackbody temperature, °C
17	Silicon focal-plane assembly (FPA),°C
18	Calibration shutter flag temperature, °C
19	NASA use
20	Baffle temperature, °C
21	Cold focal-plane assembly monitor temperature,°K
22	NASA use
23	NASA use
24	Scan-line corrector temperature, °C
25	Calibration shutter hub temperature, °C

Word 72 of Minor-Frame Number	Description
26	NASA use
27	NASA use
28	Relay optics temperature, °C
29	NASA use
.	
.	
.	
39	NASA use
40	Primary mirror temperature, °C
41	NASA use
42	Secondary mirror temperature, °C
43	NASA use
44	NASA use
45	NASA Use
46	NASA Use

The words in minor-frame numbers 17 and 18 are used for two sensors with different calibration. The shutter surface (flag) temperature is used for Band 6 calibrations, and the hub temperature is currently undetermined.

Each telemetry function can be converted from counts (C) to engineering units (EU) by using the following equation:

$$EU = A_0 + A_1C + A_2C^2 + A_3C^3 + A_4C^4 + A_5C^5$$

The units and coefficients for each telemetry point follow.

Blackbody temperature: degrees centigrade

$A_0 = 12.44$ $A_1 = 0.1326$ $A_2 = -0.1604 \times 10^{-4}$
$A_3 = 0.1416 \times 10^{-5}$ $A_4 = -0.6519 \times 10^{-8}$ $A_5 = 0.1812 \times 10^{-10}$

Silicon FPA temperature: degrees centigrade

$A_0 = 8.992$ $A_1 = 0.1011$ $A_2 = -0.1595 \times 10^{-4}$
$A_3 = 0.3605 \times 10^{-6}$ $A_4 = 0.0$ $A_5 = 0.0$

Calibration shutter temperature: degrees centigrade

$A_0 = 35.37$ $A_1 = -0.1670$ $A_2 = 0.1404 \times 10^{-3}$
$A_3 = -0.3630 \times 10^{-6}$ $A_4 = 0.0$ $A_5 = 0.0$

Backup shutter temperature: degrees centigrade

$A_0 = 35.37$ $A_1 = -0.1670$ $A_2 = 0.1404 \times 10^{-3}$
$A_3 = -0.3630 \times 10^{-6}$ $A_4 = 0.0$ $A_5 = 0.0$

Baffle temperature: degrees centigrade

$A_0 = -4.040$ $A_1 = -0.3913$ $A_2 = -0.7061 \times 10^{-2}$
$A_3 = 0.6710 \times 10^{-4}$ $A_4 = -0.2671 \times 10^{-6}$ $A_5 = 0.3701 \times 10^{-9}$

Cold stage FPA temperature: degrees kelvin

$A_0 = 110.0$ $A_1 = -0.1000$ $A_2 = 0.0$
$A_3 = 0.0$ $A_4 = 0.0$ $A_5 = 0.0$

Scan-line corrector: degrees centigrade

$A_0 = 120.6$ $A_1 = -1.899$ $A_2 = 0.01918$
$A_3 = -0.1191 \times 10^{-3}$ $A_4 = 0.3789 \times 10^{-6}$ $A_5 = -0.4907 \times 10^{-9}$

Calibration shutter temperature: degrees centigrade

$A_0 = 120.6$ $A_1 = -1.899$ $A_2 = 0.01918$
$A_3 = -0.1191 \times 10^{-3}$ $A_4 = 0.3789 \times 10^{-2}$ $A_5 = 0.4907 \times 10^{-9}$

Relay optics temperature: degrees centigrade

A_0 = -121.23 A_1 = -1.9147 A_2 = 0.014275
A_3 = 0.11865×10^{-3} A_4 = 0.37343×10^{-6} A_5 = -0.47899×10^{-9}

Primary mirror temperature: degrees centigrade

A_0 = -121.23 A_1 = -1.9147 A_2 = 0.014275
A_3 = 0.11865×10^{-3} A_4 = 0.37343×10^{-6} A_5 = -0.47899×10^{-9}

Secondary mirror temperature: degrees centigrade

A_0 = -121.23 A_1 = -1.9147 A_2 = 0.014275
A_3 = 0.11865×10^{-3} A_4 = 0.37343×10^{-6} A_5 = -0.47899×10^{-9}

Note: Telemetry conversions can change and are instrument unique.

1. Spare Telemetry--Up to 176 bits of telemetry data may be stripped out and output in telemetry in the same manner as the TM housekeeping data except the fourth transfer period will be used. (See Figure 17.)

The data will appear in word 72 of minor frames 28 through 49 of the first PCD major frame after the telemetry major-frame pulse. (See Figure 13.) This major frame carries the spacecraft time code.

The data will be from the telemetry major frame that started 32.768 seconds before the time given in the PCD major frame.

At present, four 8-bit words have been defined as shown in Table 9a.

Table 9a
Spare Telemetry in PCD Subcom (Word 72)

Minor Frame	Function		
28	Ephemeris Source Identification	$(00)_{16}$ = GPS $(01)_{16}$ = Uplink	
29	Roll Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below
30	Pitch Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below
31	Yaw Gyro Identification	$(00)_{16}$ = Gyro 1 $(01)_{16}$ = Gyro 2	See Below

IRU Channel

	Gyro 1	Gyro 2
Roll	B	A
Pitch	B	C
Yaw	A	C

m. <u>MUX Status</u>--A "Frame Error Bit" is transmitted as the MSB of word 72 of minor frame 116 of each PCD major frame (see Figure 15a). A digital zero indicates that the expected telemetry major frame pulse either did not occur or did not line up with the start of the first PCD major frame.

n. <u>A/D Ground Reference</u>--The output of the Angular Displacement Sensor Assembly (ADSA) A/D Converter for a grounded input is transmitted in word 72 of minor frame 116 and 117 of each PCD major frame (Figure 13a).

5.4.8 High-Resolution Data

The high-resolution sensor data usually follows the PCD word and completes the minor frame. The format is always 96 8-bit words unless pre-empted by the next SLS. During the first six minor frames following the SLS, these data slots are taken up with time-

code information. All time, picture, and calibration data words are PN-encoded.

5.4.9 Time Code

The time-code information contained in the first six minor frames after SLS represents the time of the scan-line start. Time-code minor frames contain 102 8-bit words. The first four words are dedicated to minor-frame sync. The minor-frame sync word is:

MSB (output first)
0000 0010 0011 0111 0001 0110 1101 0001
LSB

Time is binary-coded decimal (BCD) days and Greenwich mean time (GMT) hou , minutes, seconds, milliseconds, and 1/16 millisecond. A 4-bit spacecraft identifier is included within the time code. Table 8 hows the output format of the first six-minor frames of each major frame (i.e., set of 16 scan lines).

5.4.10 Midscan Code Format

If enabled by command, a midscan code will replace portions of the data in the last 96 words of a scene data minor frame. The midscan code consists of 48 words of white (level 255) data followed by 48 words of black (level 0) data. The midscan code will start within two to nine words of the second scan-angle monitor pulse following scan-line start, which will occur approximately in minor frame 3160. The midscan code can interrupt scene data at word boundaries and need not be coherent with a minor frame. In most cases, the midscan code will occupy portions of two minor frames. The midscan code does not replace minor-frame sync, band 6, and PCD words. Midscan code data are PN-encoded, have the four LSB's inverted, and are output MSB first. NASA plans to use the midscan code to develop

and/or validate the mirror velocity profile and mirror scan repeatability. NASA intends to use this mode infrequently on a noninterference basis with foreign acquisition requirements. Upon special request, foreign ground stations could receive MSS or TM imagery with mid-scan code enabled. For TM, this is unnecessary because first half scan time error and second half scan time error is included in the line length code described in Section 5.4.13. This line length code is part of the X-band data.

5.4.11 End of Scan

When the end-of-scan pulse occurs, approximately 6320 minor frames into the major frame, the TM will generate 48 words of dark (level 0), followed by 48 words of bright (level 255), 48 words of dark, and 48 words of bright in sequence. These words will replace the high-resolution data in the current minor frames but not the minor-frame sync, band-6 sensor, or PCD. The first bit of end-scan code occurs within two to nine word times of the TM mirror scan-angle monitor pulse. The end-scan code is not coherent with the minor frame, but does start on an 8-bit word boundary. It replaces scene data as required, but does not replace minor-frame sync, band 6, and PCD or frame-counter words. The 192 words of end-scan code will usually occupy portions of three minor frames. End-scan code data are PN-encoded, four LSB's inverted, and output MSB first.

Insertion of this end-of-scan code will allow determination of end of scan by the ground systems. The end-of-scan pattern is followed by line length and scan direction information in the first two complete minor frames following the end of scan black-and-white bars. This scan-line length and direction refers to the scan before the one in which they are included (e.g., the line length and scan direction data appended to scan n+1 describes scan n). After this, the normal video data are output for about 10 milliseconds while the

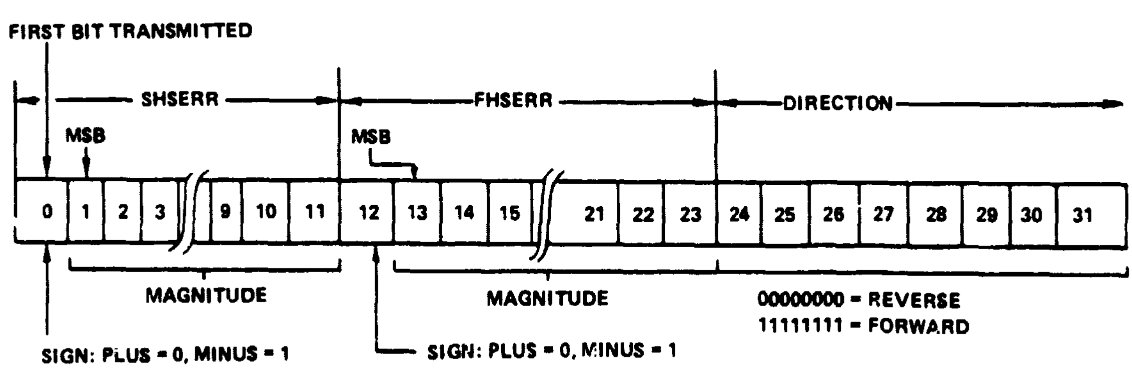
calibration and zero restore shutter is scanned. The format of calibration data and DC restore data in a minor frame is the same as that of the scene data. All words in the format, except for minor-frame sync, scan-line start, and not pseudonoise ($\overline{PN}$), will have the last four bits inverted and will then be PN-encoded. The last millisecond of each scan will have the high-resolution video words replaced by the complement of the PN code ($\overline{PN}$) and may be used to measure data-line bit-error rates (BER). (See Table 7 for a list of the timing and minor-frame word counts for end of scan.)

5.4.12 Line-Length Data

The TM high-rate data stream contains a line-length code that indicates the time from line start to midscan, the time from midscan to line stop, and scan direction.

5.4.13 Line-Length Code

The scan mirror assembly transmits a 32-bit serial data word to the multiplexer at the end of each scan (Figure 18). As indicated, each bit of the 32-bit line-length code is repeated 47 times and encoded in six consecutive 8-bit bytes (48 bits total). In the scan angle monitor mode, the data are as follows:



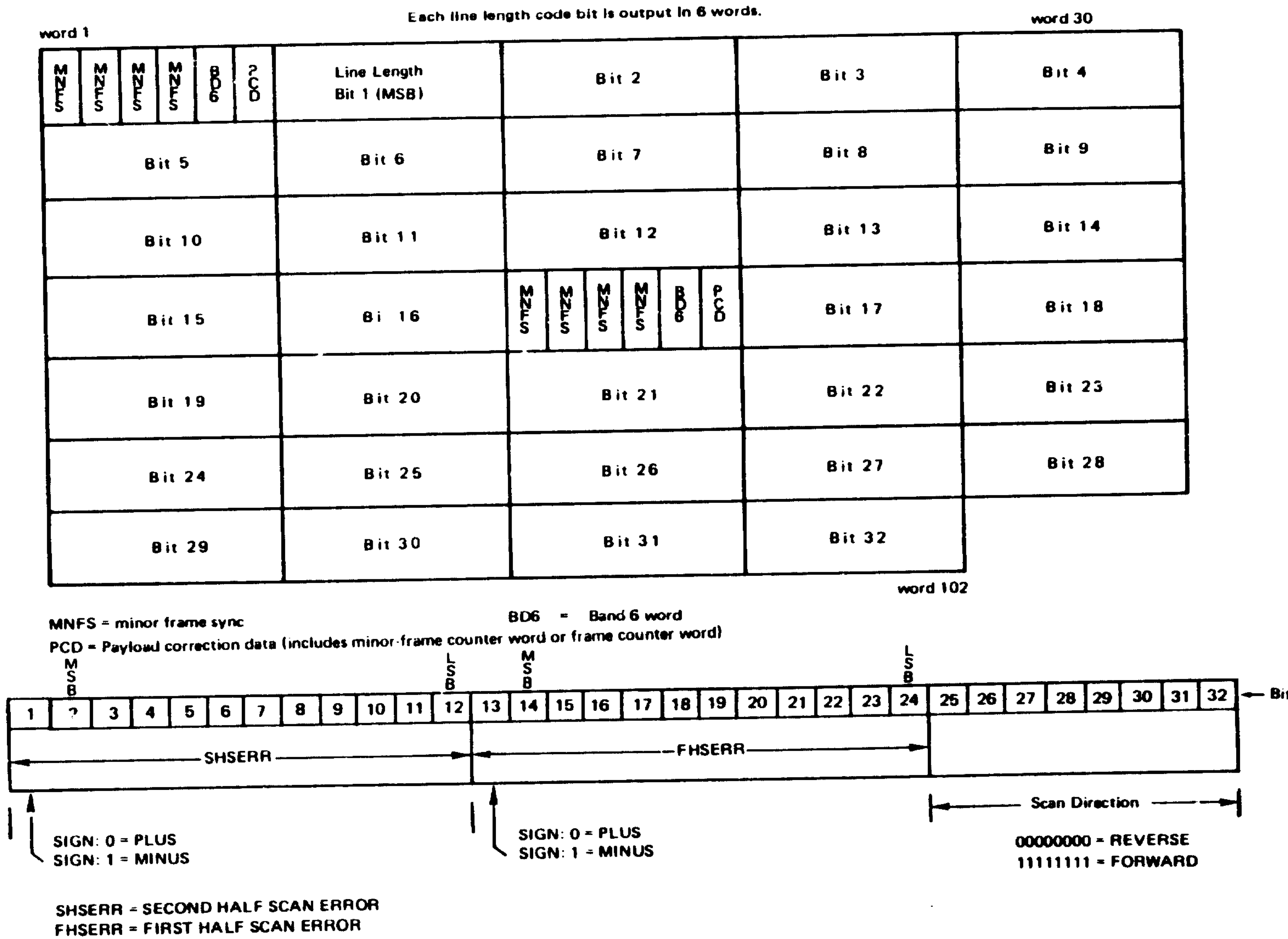


Figure 18. Line-Length Format

The units of magnitude are clock pulses where the clock rate is 1/16 the TM 84.903 bit rate. Minus magnitudes are given in 2's complement notation.

SHSERR = time error in clock counts from the nominal midscan to line stop count of 161,165

FHSERR = time error in clock counts from the nominal line start to midscan count of 161,164

For example, a typical engineering model sample is:

000000100100	1111111011101	00000000
Decimal = 36	Decimal = -35	Reverse

SHSERR = (36) (1/(84.903/16)) = 6.78 microseconds
FHSERR = (-35) (1/(84.903/16)) = -6.60 microseconds

Active scan time = ((161,165 + 161,164) + (SHSERR + FHSERR))
x (1 (84.903 16) = 60,743 microseconds

5.4.14 Postamble Data

Postamble data commence at the 960th minor frame following end-scan code. Postamble will continue for approximately 1 millisecond,

until it is interrupted by major-frame sync. Major-frame sync will interrupt only at word boundaries. Postamble minor frames contain the standard minor-frame sync (4), band-6 data, and PCD words. The remaining words of each minor frame shall contain the inverse of the PN-code shown in Figure 9. The inverse PN-code data are not encoded. The PN data start with the 49th bit of the pattern and are reset at each minor frame. (Refer to Table 6 for a list of timing and minor-frame word counts for postamble.)

5.4.15 Shutter Obscuration Period

After transmission of the line length and the scan direction data, sensor data will be output until the sinusoidally oscillating shutter obscures the optical path to the detectors. During this period, the internal calibration and dc restoration data are transmitted as described in paragraph 5.3. Table 7 provides approximate start-and end-time periods when calibration and dc restoration occur for both the forward and reverse scans. Refer to Table 7 for minor-frame shutter obscuration timing.

5.5 TM DATA PROCESSING CONSTANTS

The values of certain spacecraft and sensor constants required in ground processing are provided in Appendix C.

6. TELEMETRY FORMAT

For Landsat-D, there will be two fixed telemetry formats, one engineering format, and one mission format. Both formats can operate at 1 kbps or 8 kbps. The mission format will be transmitted to ground stations at 8 kbps. A minor telemetry frame consists of 1024 bits that represent 128 8-bit words. Sixteen of the 128 words are in a fixed position and are located symmetrically in the format as four groups of four words each. A major frame consists of 128 minor frames.

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6.1 REAL-TIME TELEMETRY AND PAYLOAD CORRECTION DATA FORMATS FOR GSTDN BACKUP STATIONS AND FOREIGN GROUND STATIONS

The real-time spacecraft telemetry (i.e., housekeeping and OBC data reports) and the PCD are downlinked by the S-band transponder. The foreign ground stations can use either the real-time spacecraft telemetry or the PCD only, or they may use both. The data control and formats of these two data types are described in Section 7 and Section 5.4.7, respectively. (Refer to paragraph 9.4 for the S-band omni downlink characteristics.)

6.2 BIT RATE

The output bit rates for direct telemetry data transmission to Ground Spaceflight Tracking Data Network (GSTDN) and foreign ground stations are shown in Table 10.

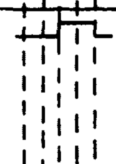
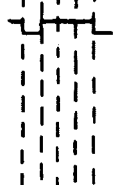
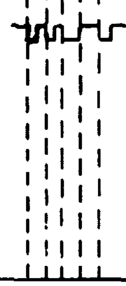
Table 10
Telemetry Bit Rates

Telemetry Type	Bit Rate (kbps)	Receiving Site
Real-time spacecraft telemetry	8	GSTDN or foreign stations
Payload correction data	32	GSTDN or foreign stations

6.3 MODULATION TECHNIQUE

The real-time spacraft telemetry is biphase-M phase-shift keyed, pulse-modulated (BIφ-M/PSK/PM) on a 1.024-MHz subcarrier by the omni antenna. Twenty percent of the power is in the residual carrier. The PCD is BIφ-M/PM directly on the base band. The biphase-M and NRZ data formats are described and shown in Table 11.

Table 11
Data Bit Stream Formats

Data Format	...11001...	Description
NRZ-L		NRZ level (or NRZ change): "ONE" is represented by one level. "ZERO" is represented by the other level.
NRZ-M		NRZ-mark (differential encoding): "ONE" is represented by a change in level. "ZERO" is represented by no change in level.
BIΦ-M		Biphase, a transition occurs at the beginning of every time (T) period. "ONE" is represented by a second transition one-half time period later. "ZERO" is represented by no second transition.

6.4 WORD LENGTH

The word length is 8 bits assembled into analog, passive analog, bilevel (discrete), or serial digital.

6.5 FORMATS

Three formats are supported by Landsat-D: Format I (engineering), Format II (mission), and Format III (OBC dump). The mission format is to be used by GSTDN and foreign stations in the normal on-orbit payload activity. The engineering format is to be used by NASA when the spacecraft is deployed in an orbit-adjust or safe-hold activity, and the OBC dump is to be used by NASA to maintain and verify OBC software.

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7. MISSION FORMAT TELEMETRY

This section describes the Landsat-D Mission telemetry data to be provided to the foreign ground stations.

7.1 TELEMETRY FRAME FORMAT

Table 12 presents the minor-frame word (column) allocations for the mission format. Each minor-frame word is sampled every 128 milliseconds at 8 kbps. Ten minor-frame words (i.e., columns 0, 1, 2, 3, 34, 35, 64, 65, 66, and 67) are reserved for specific spacecraft data and are designated as fixed words. Six words (i.e., 32, 33, 96, 97, 98, and 99) have been allocated for subcommutated data so that data are sampled at least once every major frame. Twenty-five additional words in each minor frame (i.e., columns 91 to 95 and 108 to 127) have been reserved for OBC reports.

7.2 TELEMETRY FORMAT

7.2.1 Major Frame

The major-frame telemetry format is a 128- by 128-column matrix. A minor frame (row) contains 128 8-bit words (columns) and is shown in Table 12. A major frame consists of 128 minor frames. The format starts in row 0, column 0 and proceeds sequentially through the matrix until the final word in row 127, column 127 is transmitted, thus completing a major frame. The MSB is transmitted first in a minor-frame word. The major-frame duration is 16.384 seconds at 8 kbps.

7.2.2 Minor Frame

Each minor frame contains 128 words. The first three words are used for the minor-frame synchronization. The minor-frame counter is located in word location 65. These data words are located in fixed word locations as shown in Table 13. At the 8-kbps rate, a word period is 1 millisecond.

Table 12
Mission Format Telemetry Matrix Construction

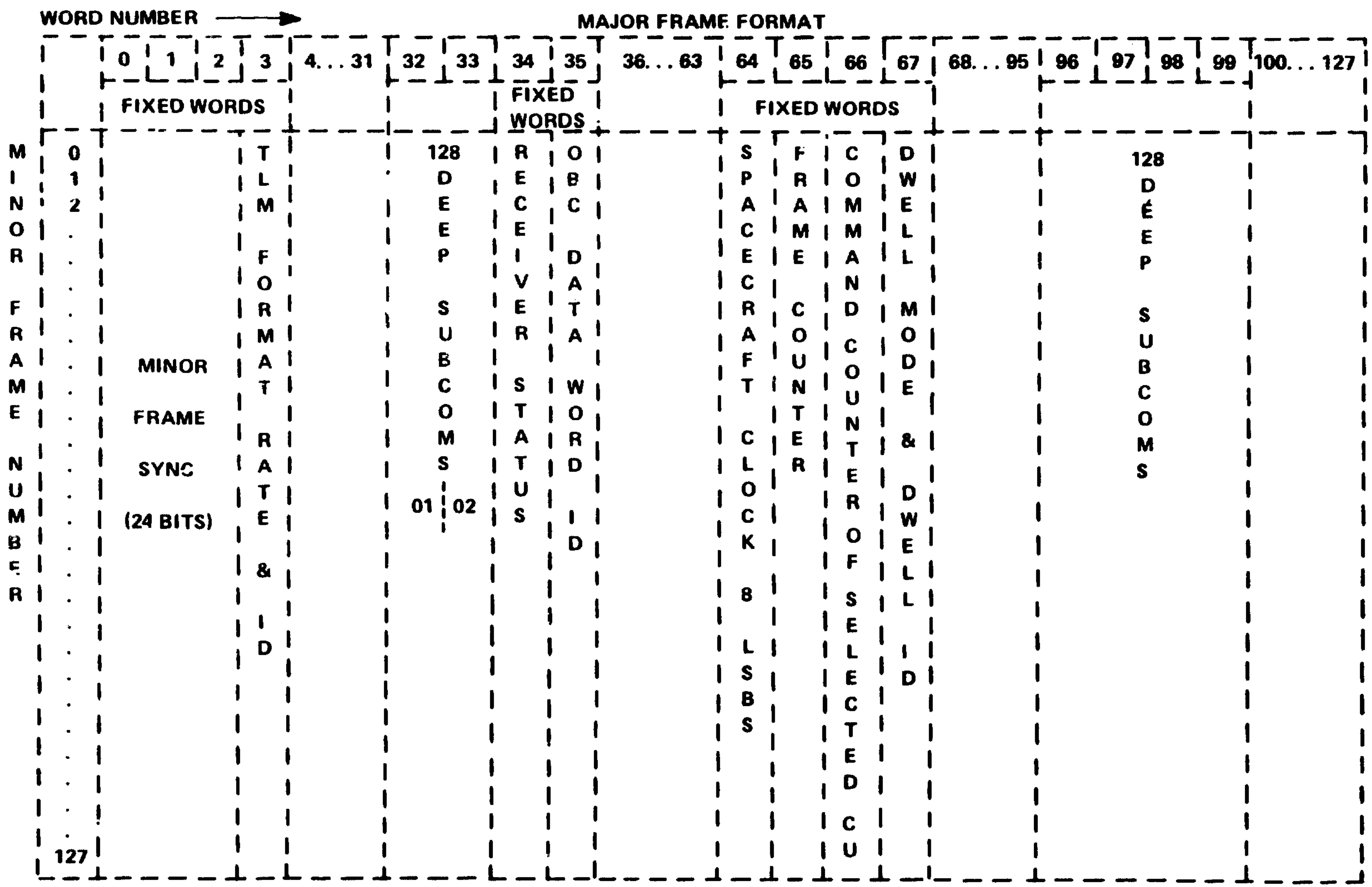

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Table 13
Mission Format Fixed-Column Assignments

Word Number	Bit Number	Function
0-2		Sync word (FAF320 in hexadecimal)
3	0, 1, 2 3, 4 6	Bit rate Format ID Real-time/computer dump data
32		Subcom 01
33		Subcom 02
35		Computer data word (report identifier)
65		Frame counter
91-95		Subcom OBC reports, data words 1-5
96		Subcom 03
97		Subcom 04
98		Subcom 05
99		Subcom 06
108-127		Subcom OBC reports, data words 6-25

7.2.3 Telemetry Control Words

7.2.3.1 Synchronization--The first three words in each minor frame are used for minor-frame synchronization. These 24 sync bits are described as follows:

WORD 0 MSB	WORD 1	WORD 2 LSB
11111010	11110011	00100000

Since the telemetry bit stream is transmitted MSB first, this sync pattern is received as shown. In hexadecimal, the sync pattern is $FAF320_{16}$.

7.2.3.2 Frame Counter--Word 65 of the minor frame is the frame counter. AT the end of each minor frame, the counter is incremented by one, and the new value (n+1) is placed in word 65 in the subsequent minor-frame counter location. This process is continued until a maximum count of 255 is reached and the process is repeated. Only the seven LSB's are needed to determine the frame-counter contents for subcom word ID (0 to 127). The bit pattern sequence is shown in Figure 14.

7.2.3.3 Other Control Words--There are two other control words in each telemetry minor frame that may be required in ground processing. The contents of these words are described below and in the following paragraphs:

a. Word 3

(1) Bit race (bits 0, 1, and 2):

000 = 1 kbps

(2) Format ID (bits 3 and 4):

01 = format I (engineering), for NASA use only
10 = format II (mission)
11 = OBC controlled, for NASA use only

(3) Real-time computer data dump (bit 6)

0 = OBC dump, for NASA use only
1 = real-time spacecraft/normal payload operation

b. Word 35 - Computer Data Word ID (8-bits)--Identifies the OBC report number contained in this minor frame. The 25-word OBC contribution to telemetry minor-frame word locations 91 to 95 and 108 to 127 can be identified by this means.

7.2.3.4 Subcommutation Mission Format--There are a total of 31 subcommutated words in a minor frame. The length of the subcommutation cycle is one full major frame. The 7-bit (0 to 127) minor-frame counter contained in word 65 is used to identify subcom words 32, 33, and 96 through 99. Words may be sampled in these columns one or more times per major frame. For example, a telemetry word assigned a sample rate of once per major frame will be sampled approximately once very 16 seconds at 8 kbps. Those words that require sampling faster than once per major frame have been equally spaced in subcom columns. As an example, a word requiring four samples per major frame is sampled first in minor frames N, second in minor-frame N+32, third in N+64, and fourth in N+96. The OBC reports contained in words 91 to 95 and 108 to 127 are subcommutated as a group, and are indexed to the OBC report number contained in word 35.

7.2.3.5 Nonfixed Columns--There are 112 other columns in the mission format for the assignment of subsystem telemetry data.

7.2.4 Telemetry Assignments by User

Tables 14 and 15 through 20 list the telemetry data of interest to Landsat-D ground station operators. Table 14 gives a telemetry function description and location in the telemetry matrix for data sampled in each minor frame, and Tables 15 through 20 cover the six subcommutators. See Section 8 for a description of the contents of OBC reports.

Table 14
Mission Telemetry Frame Format

Minor Frame Word	Description	Minor Frame Word	Description	Minor Frame Word	Description
00	Minor frame sync word 00	43		85	
01	Minor frame sync word 01	44	Calibration lamp 1 current	86	
02	Minor frame sync word 02	45	Calibration lamp 2 current	87	
03	Telemetry rate format, ID	46	Calibration lamp 3 current	88	
04		47	Blackbody temperature	89	
05		48	Silicon focal plan assembly (FPA) temperature	90	
06		49	Calibration shutter temperature	91	OBC data word 1
07		50	Backup shutter temperature	92	OBC data word 2
08		51	Cold stage FPA temperature	93	OBC data word 3
09		52	SLC temperature	94	OBC data word 4
10		53	Baffle temperature	95	OBC data word 5
11		54		96	Subcommutation 03
12		55		97	Subcommutation 04
13		56		98	Subcommutation 05
14		57		99	
15		58		100	
16		59		101	
17		60		102	
18		61		103	
19		62		104	
20		63		105	
21		64		106	
22		65	Minor-frame counter	107	
23		66		108	OBC data word 6
24		67		109	OBC data word 7
25		68		110	OBC data word 8
26		69		111	OBC data word 9
27		70		112	OBC data word 10
28		71		113	OBC data word 11
29		72		114	OBC data word 12
30		73		115	OBC data word 13
31		74		116	OBC data word 14
32	Subcom 01	75		117	OBC data word 15
33	Subcom 02	76		118	OBC data word 16
34		77		119	OBC data word 17
35	OBC data identifier	78		120	OBC data word 18
36	Subcommutator 01	79		121	OBC data word 19
37		80		122	OBC data word 20
38		81		123	OBC data word 21
39		82		124	OBC data word 22
40		83		125	OBC data word 23
41		84		126	OBC data word 24
42				127	OBC data word 25

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Table 15
Subcommutator 01--Minor Frame Word 32

Minor Frame	Description	Minor Frame	Description
00	Time-code word 1	33	
01	Time-code word 2	⋮	
02	Time-code word 3	50	Calibration lamp 3 current
03	Time-code word 4		
04	Time-code word 5	⋮	
05	Time-code word 6	74	Blackbody temperature
06	Time-code word 7	75	Silicon focal-plane assembly temperature
07		⋮	
08			
09		78	Calibration shutter flag temperature
10		79	Calibration shutter hub temperature
11		⋮	
12	Calibration lamp 1 current		
13		87	Baffle temperature
14		⋮	
15			
16		89	Cold focal-plane assembly monitor
17	All calibration lamps on		temperature
18		⋮	
19			
20		92	Relay optics temperature
21		⋮	
22			
23		98	Primary mirror temperature
24		⋮	
25			
26		100	Secondary mirror temperature
27		⋮	
28		112	Scan-line corrector temperature
29			
30		⋮	
31	Calibration lamp 2 current		
32		128	

Table 16
Subcommutator 02—Minor Frame Word 33

Minor Frame	Description	Minor Frame	Description
00		33	
01		34	
02		35	
03		36	
04		37	
05		38	
06		39	MSS band 1 channel A video (analog voltage monitor for detector 1)
07			
08		40	
09		41	
10		42	
11		43	
12		44	
13		45	MSS band 2 channel A video (detector 7)
14		46	
15		47	
16		48	
17		49	
18		50	
19		51	MSS band 3 channel A video (detector 13)
20		52	
21		53	
22		54	
23		55	
24		56	
25		57	MSS band 4 channel A video (detector 19)
26			
27			
28			
29			
30			
31		128	
32			

Table 17
Subcommutator 03-Minor Frame Word 96

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 706 = MSS system power A on/off (bit 0) MSS system power B on/off (bit 1)	31	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30		128	

Table 18
Subcommutator 04--Minor-Frame Word 97

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 801: MSS multiplexer COMPRESSED/LINEAR (Bit 6)	31	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30		128	

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Table 19
Subcommutator 05--Minor-Frame Word 98

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 802: MSS band 1 gain HIGH/LOW (bit 0) MSS band 2 gain HIGH/LOW (bit 1) MSS band 1 low voltage ON/OFF (bit 2) MSS band 2 low voltage ON/OFF (bit 3) MSS band 3 low voltage ON/OFF (bit 4) MSS band 4 low voltage ON/OFF (bit 5)	27	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26		128	

Table 20
Subcommutator 06--Minor-Frame Word 99

Minor Frame	Description	Minor Frame	Description
00	Bilevel word 803: MSS high voltage ON/OFF (bit 0) MSS band 1 high voltage A ON/OFF (bit 1) MSS band 1 high voltage B ON/OFF (bit 2) MSS band 2 high voltage A ON/OFF (bit 3) MSS band 2 high voltage B ON/OFF (bit 4) MSS band 3 high voltage A ON/OFF (bit 5) MSS band 3 high voltage B ON/OFF (bit 6)	26	
01			
02			
03			
04			
05			
06			
07			
08			
09			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25		128	

8. ONBOARD COMPUTER REPORTS

The OBC contributes 128 reports to each telemetry major frame and 1 report to each telemetry minor frame. The length of the reports are mission unique, but must be at least two words long. The first word is output in column 35 and gives the report number; the remaining word or words give the data being reported. The Landsat-D flight software contribution to telemetry are presented in this section. The OBC data items contained in the telemetry stream and their output rates are listed along with the format of the reports as they appear in the telemetry minor frames.

The number of OBC reports generated by the various flight elements, as well as the rate at which the reports are output per major frame, are tabulated in Tables 22 and 23 and Figures 19 through 23. The "Samples/Major-Frame" (Table 21 and 23) column contains the total reports contributed by each processor to each major frame. The Landsat-D flight software will contribute 103 reports to each major frame of telemetry, 17 of which are useful in ground processing of image data. This leaves 25 reports as a reserve for growth in the number of OBC data items contributed to telemetry. Each report will be 25 words long. The rate at which the various reports are output ranges from one to eight times per major frame. The order in which the OBC reports are output is defined in Table 21. Most of the data in Reports 1, 2, 10, and 11 are intended primarily for operation of the spacecraft and for engineering purposes. Emphemeris and attitude data in the OBC reports are the same as in the PCD subcom except for sampling rate. The epoch for the gyro data examples, attitude estimates, and ephemeris is defined by the parameter TF in ACS Report No. 11. The ACS telemetry is given in Table 22 and Figures 19 through 22. The ephemeris computation telemetry report is given in Figure 23 and Table 23.

Table 21
Onboard Computer Telemetry Report Sequence

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
0				
1				
2				
3				
4				
5				
6				
7				
8	1	Attitude control system (ACS) telemetry report	1	Contains θx, θy, θz
9	2	ACS telemetry report	2	Contains errors
10				
11				
12				
13				
14				
15				
16	13	Ephemeris computation TLM	1	See Fig. 23
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27	10	ACS telemetry report	10	
28				
29				
30	11	ACS telemetry report	11	
31				
32				
33				
34				
35				
36				
37				
38				
39				
40	1	ACS telemetry report	1	

C - 2

Table 21 (Continued)

Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
41	2	ACS telemetry report	2	
42				
43				
44				
45				
46				
47				
48	13	Ephemeris computation TLM	1	
49				
50				
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				
61				
62	11	ACS telemetry report	11	
63				
64				
65				
66				
67				
68				
69				
70				
71				
72	1	ACS telemetry report	1	
73	2	ACS telemetry report	2	
74				
75				
76				
77				
78				
79				
80	13	Ephemeris computation TLM	1	
81				
82				
83				

Table 21 (Continued)

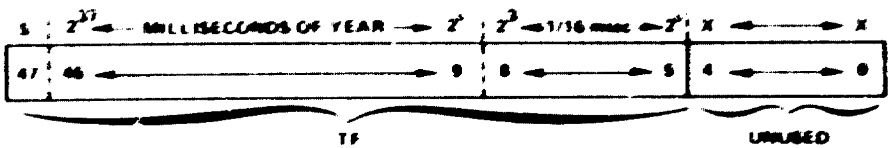
Minor Frame	OBC Report Number (Column 35)	OBC Telemetry Contents	Telemetry Report Number	Notes
84				
85				
86				
87				
88				
89				
90				
91				
92				
93				
94	11	ACS telemetry report	11	
95				
96				
97				
98				
99				
100				
101				
102				
103				
104	1	ACS telemetry report	1	
105	2	ACS telemetry report	2	
106				
107				
108				
109				
110				
111				
112	3	Ephemeris computation TLM	1	
113				
114				
115				
116				
117				
118				
119				
120				
121				
122				
123				
124				
125				
126	11	ACS telemetry report	11	
127				

Table 22
ACS Telemetry

Symbol	Definition	OBC Report	Samples/ Major Frame	Number of Bytes	Range	Unit	LSB Weight
θ_x	Roll axis angular increment (rad)	1	4	2	±1.79	rad	5.6E-6
θ_y	Pitch axis angular increment (rad)	1	4	2	±1.79	rad	5.46E-6
θ_z	Yaw axis angular increment (rad)	1	4	2	±1.79	rad	5.46E-6
ω_x	Roll axis angular rate (rad/sec)	2	4	1	±1.776	rad/sec	0.014
ω_y	Pitch axis angular rate (rad/sec)	2	4	1	±1.776	rad/sec	0.014
ω_z	Yaw axis angular rate (rad/sec)	2	4	1	±1.776	rad/sec	0.014
E_x	Roll attitude error	2	4	2	±3.99	rad	1.22E-4
E_y	Pitch attitude error	2	4	2	±3.99	rad	1.22E-4
E_z	Yaw attitude error	2	4	2	±3.99	rad	1.22E-4
EPA 1	Euler parameters that specify vehicle orientation relative to Earth-centered inertial frame	2	4	3	±2	ND	2.38E-7
EPA 2		2	4	3	±2	ND	2.38E-7
EPA 3		2	4	3	±2	ND	2.38E-7
EPA 4		2	4	3	±2	ND	2.38E-7
θ_{Bx}	Roll gyro bias compensation (rad)	10	1	2	±3.147	rad	9.6E-5
θ_{By}	Pitch gyro bias compensation (rad)	10	1	2	±3.147	rad	9.6E-5
θ_{Bz}	Yaw gyro bias compensation (rad)	10	1	2	±3.147	rad	9.6E-5
TF	Flight software time	11	4	6	2.748E8	msec	1/16 msec

ND - NONDETERMINED

TF FORMAT



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TLM Word	1	2	3	4	5
OBC Data	MSB θ_x	LSB	MSB θ_Y	LSB	θ_z

	6	7	8	9	10
	LSB				

	11	12	13	14	15

	16	17	18	19	20

	21	22	23	24	25

Output four times per major frame in minor frames 8, 40, 72, and 104.
Sixteen MSB's of double precision θx, θy, θz are downlinked.

Figure 19. ACS Telemetry Report 1

<table>
<tr><td>TLM Word</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>OBC Data</td><td colspan="3"></td><td>Wx</td><td>Wy</td></tr>
<tr><td></td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr>
<tr><td></td><td>Wz</td><td colspan="2">Ex</td><td colspan="2">Ey</td></tr>
<tr><td></td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td></td><td colspan="2">Ez</td><td colspan="3">EPA1</td></tr>
<tr><td></td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td></tr>
<tr><td></td><td colspan="3">EPA2</td><td colspan="2">EPA3</td></tr>
<tr><td></td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td></tr>
<tr><td></td><td>EPA3</td><td colspan="3">EPA4</td><td></td></tr>
</table>

Output four times per major frame in minor frames 9, 41, 73, and 105.
Eight MSB's of single precision Wx, Wy, Wz are downlinked.
Sixteen MSB's of double precision Ex, Ey, Ez, are downlinked.

Figure 20. ACS Telemetry Report 2

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TLM Word	1	2	3	4	5
OBC Data	MSB θ_{bx}	LSB	MSB θ_{by}	LSB	MSB θ_{bz}

	6	7	8	9	10
	LSB				

	11	12	13	14	15

	16	17	18	19	20

	21	22	23	24	25

Output once per major frame in minor frame 27.
Sixteen MSB's of double precision θ_{bx}, θ_{by}, θ_{bz} are downlinked.

Figure 21. ACS Telemetry Report 10

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TLM Word	1	2	3	4	5
OBC Data	MSB ← T_f →				

6	7	8	9	10
LSB XXXXX				

11	12	13	14	15

16	17	18	19	20

21	22	23	24	25

Output four times per major frame in minor frames 30, 62, 94, and 126.

Notes

1) Each value of the T_f in OBC Report ACS 11 defines an epoch at which gyro data is sampled, ephemeris data is computed, and attitude is computed.

Scale = 38, Length = 42 bits preceded by sign bit, and
LSB = 1/16 millisecond

The four ACS 11 reports in each major frame correspond to the four Ephemeris report sets and the other ACS reports sampled four times per major frame.

2) T_f is the GMT milliseconds into the year as derived from the DPU clock, referenced to a value of 8.64×10^7 msec at 0000 hours GMT on January 1.

Figure 22. ACS Telemetry Report 11

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Table 23
Ephemeris Computation Telemetry Report 1

Symbol	Definition	OBC Report	Samples per Major Frame	Number of Bytes	Range	Units	LSB Weight
EOGBRF(1)	Earth centered inertial (ECI) x-axis component of flight segment (FS) position computed using predicted-fit ephemeris	13	4	4	±8.3886E6	meters	3.90625E-3
EOGBRF(2)	ECI Y-axis component of FS position computed using predicted-fit ephemeris	13	4	4	±8.3886E6	meters	3.90625E-3
EOGBRF(3)	ECI Z-axis component of FS position computed using predicted-fit ephemeris	13	4	4	±8.3886F6	meters	3.90625E-3
EOGBVF(1)	ECI X-axis component of FS velocity computed using predicated fit ephemeris	13	4	4	±8	meters/millisecond	3.72528E-9
EOGBVF(2)	ECI Y-axis component of FS velocity computed using predicated-fit ephemeris	13	4	4	±8	meters/millisecond	3.72528E-9
EOGBVF(3)	ECI Z-axis component of FS velocity computed using predicated-fit ephemeris	13	4	4	±8	meters/millisecond	3.72528E-9

* $LSB = \frac{1}{2^{N-S}}$

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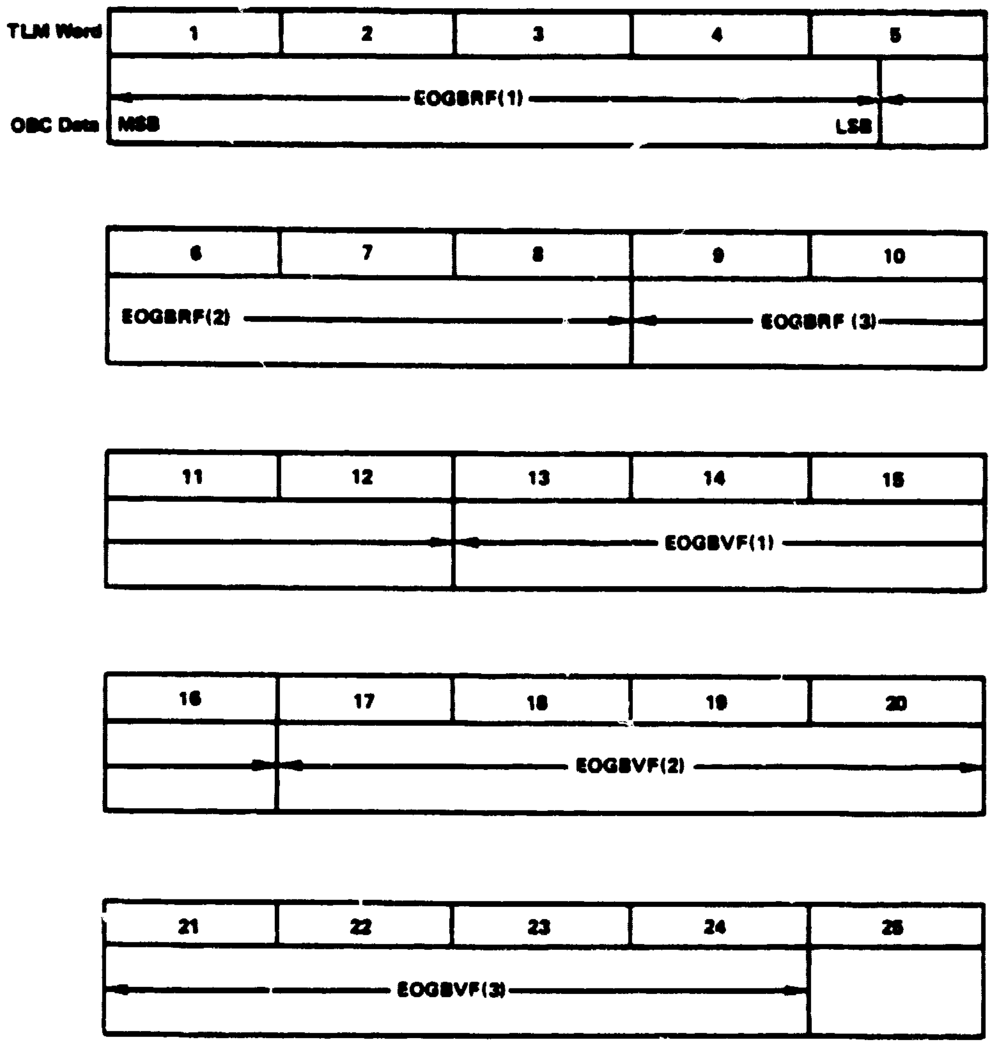

Output four times per major frame in minor frames 16, 48, 80, and 112.

Figure 23. Ephemeris Computation Telemetry Report 1

9. LANDSAT-D COMMUNICATIONS

9.1 LANDSAT-D X-BAND CHARACTERISTICS

The following information describes the Landsat-D X-band link characteristics:

a. Frequency: 8.2125 GHz

b. Transmitter power: 44 watts

c. Spacecraft antenna characteristics

- Shaped-beam antenna
- Gain at 63.8 degrees from nadir (plus 7 dB)
- Gain at nadir (minus 2 dB)
- Spacecraft connection loss: 0.6 dB

d. Modulation scheme

- Unbalanced quadrature phase-shift keyed (UQPSK)
- MSS (15.0626 Mbps) data on the Q-channel
- TM (84.903 Mbps) data on the I-channel

e. Downlink spectrum: The TM data are PN-encoded on the spacecraft. Data are spread over approximately 170-MHz bandwidth.

9.1.1 Working Mode, Modulation, and Spectral Occupation

The Landsat-D X-band transmit link uses a UQPSK modulation format for transmitting TM and MSS data. The TM data are usually modulated on the "I" carrier channel, and the MSS data on the "Q" carrier

channel with a 4 to 1 power split. There will be three operational modes that are as follows:

Mode	I-Channel	Q-Channel	Modulation
1	PN (84.903 Mbps)	MSS (15.0626 Mbps)	UQPSK
2	TM (84.903 Mbps)	TM (84.903 Mbps)	BPSK
3	TM (84.903 Mbps	MSS (15.0626 Mbps)	UQPSK

The TM data are replaced with PN code for mode 1, in which only the MSS is operating. When only the TM is operating, the MSS data may be replaced with TM data. The TM data are PN-encoded within the instrument electronics. The MSS and TM are differentially encoded by converting from NRZ-L to NRZ-M for downlink transmission.

9.1.2 Output Filter Characteristics

A low-pass filter at the output of the TWT is planned to attenuate the TWTA second harmonic as well as the output noise to a level at which it will not degrade the Ku-band forward link receiver noise figure. A pre-TWTA four-pole 0.01-dB ripple Tschebyscheff filter with a matched bandwidth of 225 MHz is provided to meet power flux density restrictions. The X-band low-pass filter characteristics are as follows:

Bandwidth: $\pm$84 MHz
Insertion loss: $\leq$0.15 dB
VSWR: 1.15:1
Phase deviation from linearity: $\leq$0.25 deg over $\pm$84 MHz
Insertion loss variation: $\leq$0.05 dB over $\pm$84 MHz
Gain slope: $\leq$0.01 dB/MHz over $\pm$84 MHz
Rejection: $\geq$31 dB at 16.4 GHz; >14 dB at 13.775 GHz

9.2 LANDSAT-D S-BAND IMAGE DATA TRANSMISSION CHARACTERISTICS

The following information describes the Landsat-D S-band image data transmission characteristics:

a. Carrier frequency: 2265.5 MHz

b. Transmitter power: 10 watts

c. Spacecraft antenna characteristics

- Shaped-beam antenna
- Gain at 63.8 degrees from nadir (+2.5 dB)
- Gain at nadir (minus 8 dB)
- Spacecraft connection loss: 1.5 dB

d. Modulation scheme

- NRZ-L PCM/FM
- MSS 15.0626 Mbps (same as Landsats 1 through 3)
- Deviation $\pm$5.6 MHz $\pm$5 percent

e. Downlink spectrum: MSS data are spread over approximately 20-MHz bandwidth.

9.3 LANDSAT-D S-BAND TELEMETRY DATA TRANSMISSION CHARACTERISTICS

The S-band telemetry will be commanded on in response to a foreign station's request for telemetry data to support their MSS image data reception by either S-band or X-band. The following information describes the Landsat-D S-band telemetry data transmission characteristics:

a. Frequency: 2287.5 MHz

b. Effective isotropic radiation power: +3.2 dBW

c. Modulation scheme: 8 kbps

- PCM/PSK/PM
- 8-kbps data on 1.024-MHz subcarrier
- Carrier modulation index: 0.8 rad

d. Modulation scheme: 32-kbps PCD

- PCM/PM
- 32-kbps PM on carrier
- Carrier modulation index: 1.0 rad
- Frequency stability and aging temperature stability
  - Combined effects over 1 year: ± 3.8 parts per 10^6
  - Short-term stability: the RMS fractional deviation for a 3-minute period, measured with a 1.0-second integration time shall not exceed 3×10^{-9}.

e. Downlink spectrum: Data are spread over approximately 3-MHz bandwidth.

9.4 LANDSAT-D X-BAND AND S-BAND COMMUNICATIONS TO FOREIGN GROUND STATIONS

Foreign ground stations can acquire TM video data by the X-band link only. PCD can be acquired by the X-band (in TM video) or S-band 32-kbps data link. MSS video data can be acquired by the X-band link in addition to the S-band link, as is currently the case with Landsat 2 and Landsat 3. MSS telemetry data can be acquired on the S-band 8-kbps link. If required, S-band and X-band communications links can be operated simultaneously to satisfy foreign ground station coverage requirements for common areas. Simultaneous S-band

and X-band ıage data transmission to one station will not be supported, although PCD transmission by S-band can be scheduled during X-band TM data transmission. The Landsat-D Flight Segment has been designed to transmit a cumulative total of 100 daytime and 50 night thematic mapper scenes to participating user ground stations.

Preliminary downlink carrier frequency stability for the X-band, S-band telemetry, and S-band image data communications links to foreign ground stations are as follows:

a. Landsat-D S-band telemetry data transmission frequency stability: ± 0.0004 percent inclusive of initial frequency setting, aging, and temperature stability effects over 1 year

b. Landsat-D X-band transmission initial setting accuracy: 82125 GHz ± 0.005 percent; frequency stability: ± 0.0004 percent after 3 years in space

c. Landsat S-band image data transmission: ± 0.0005 percent inclusive of initial frequency setting, aging, and temperature effects after 3 years in space

10. CHANNEL AND PROCEDURES FOR PROVIDING CALIBRATION DATA TO FOREIGN STATIONS

NASA/GSFC supplies calibration data to members of the Landsat Ground Station Operations Working Group (LGSOWG) only as authorized by NASA Headquarters. The following calibration data have been provided in the past to approved LGSOWG members:

a. Prelaunch mirror velocity profile

b. Postlaunch mirror velocity profiles as available

c. Prelaunch detector response curves

11. TELEMETRY TIME SIGNALS--ONBOARD CLOCK RESETTING PROCEDURE

The time of the onboard clock shall be accurate to ± 20 milliseconds relative to Universal Time Coordinated (UTC). A daily update is expected to be adequate for maintaining this clock accuracy. Time updates will not be performed during MSS or TM data acquisitions.

APPENDIX A

MULTISPECTRAL SCANNER DATA FORMAT

FOR LANDSAT-D (MARCH 1, 1979)

APPENDIX A

MULTISPECTRAL SCANNER DATA FORMAT FOR LANDSAT-D (MARCH 1, 1979)

A1. GENERAL DESCRIPTION

A1.1 MULTISPECTRAL SCANNER FORMATS

Multispectral scanner (MSS) formats described in the following paragraphs are:

- Serial bit stream following bit synchronization (i.e., input to first high-density tape recorders)
- Serial bit stream following ground segment demultiplexer (DEMUX) (input to Operations Control Center (OCC) quick-look displays)

Within the ground segment, the multiplexer (MUX) output signal is received, demodulated, and fed into a bit synchronizer to re-establish bit synchronization. The DEMUX establishes group synchronization, decommutates the data into line-scan format, generates line-length count, reinverts the middle two bits on all data, and finally generates its own preamble to the line. The MSS is capable of operating in two basic modes: compression and noncompression (linear). In addition, the MSS may be operated at different gains as shown in Table A-1. The data format does not vary depending on the mode.

A2. BIT SYNCHRONIZATION OUTPUT FORMAT

The serial data stream can be observed after bit synchronization on the ground before any further processing. Thus, it agrees with the MSS MUX output on the Landsat-D spacecraft. The data, after being encoded by the MUX, are in the format shown in Figure A-1. This

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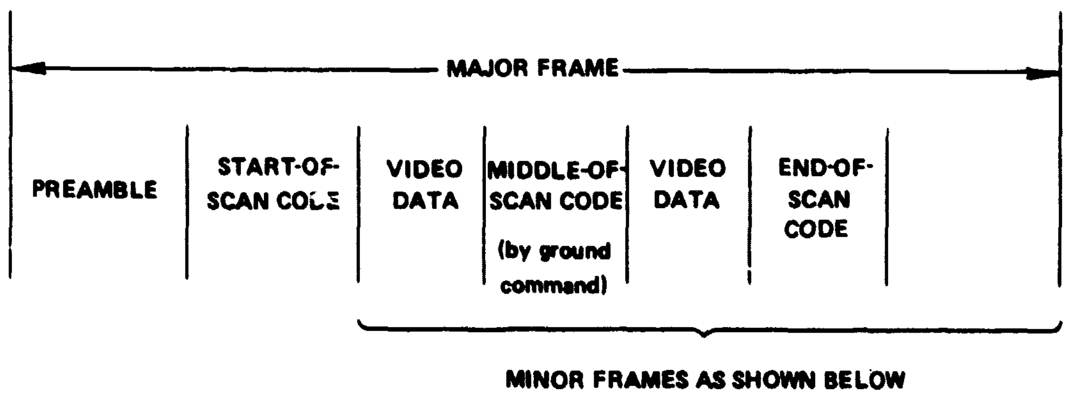

ROW = 25 WORDS

ROW 1	MNFS	SENSOR 1 (1A)	SENSOR 2 (2A)	. . . . . .	SENSOR 24 (4F)	MINOR FRAME 150 WORDS
ROW 2	(BLANK)	SENSOR 1	SENSOR 2	. . . . . .	SENSOR 24	
ROW 3	(BLANK)	SENSOR 1	SENSOR 2	. . . . . .	SENSOR 24	
ROW 4	MNFS	SENSOR 1	SENSOR 2	. . . . . .	SENSOR 24	
ROW 5	(BLANK)	SENSOR 1	SENSOR 2	. . . . . .	SENSOR 24	
ROW 6	(BLANK)	SENSOR 1	SENSOR 2		SENSOR 24	

MNFS = MINOR FRAME SYNC CODE

Note: The sampling sequence shall be 1A, 2A, 1B, 2B,...3F, 4F.

Following the start-of-scan code rows 1 and 2 of the first minor frame contain 49 words of time-code data in place of sensor data.

Figure A-1. Multiplexer Output Data Format

Table A-1
MSS Modes

Modes	Linear	Compressed	Gains IX	Gains 3X
Band 1	X	X	X	X
Band 2	X	X	X	X
Band 3	X	X	X	
Band 4	X		X	

format, which defines the details of one major frame of data containing 184,320 6-bit words, corresponds to one scan of the MSS scan mirror. Figure A-1 also shows a typical minor frame, 150 words output serially during the sensor data interval, that contain the 6- by 25-word matrix. The data rate is approximately 15.06 Mbps, which agrees with a data-word rate of approximately 2.5 by 10^6 words per second. The five segments of the major-frame format plus the calibration data format, are discussed in the following subsections. Figure A-2 and Table A-2 are provided as reference for timing, coding, and other specifics.

A2.1 PREAMBLE

The start of the preamble defines the start of the major frame. The pattern is 000111 repeated at the data word rate. The preamble is terminated at the end of the word period during which the start of scan monitor pulse is received from the scanner.

A2.2 START-OF-SCAN CODE

The single word following the termination of the preamble is the start of the scan (SMC-1) code pattern, 111000, which appears in the data stream immediately after a preamble word. Thus, an indication of the line start (i.e., beginning of active scan) is the appearance of six adjacent ones.

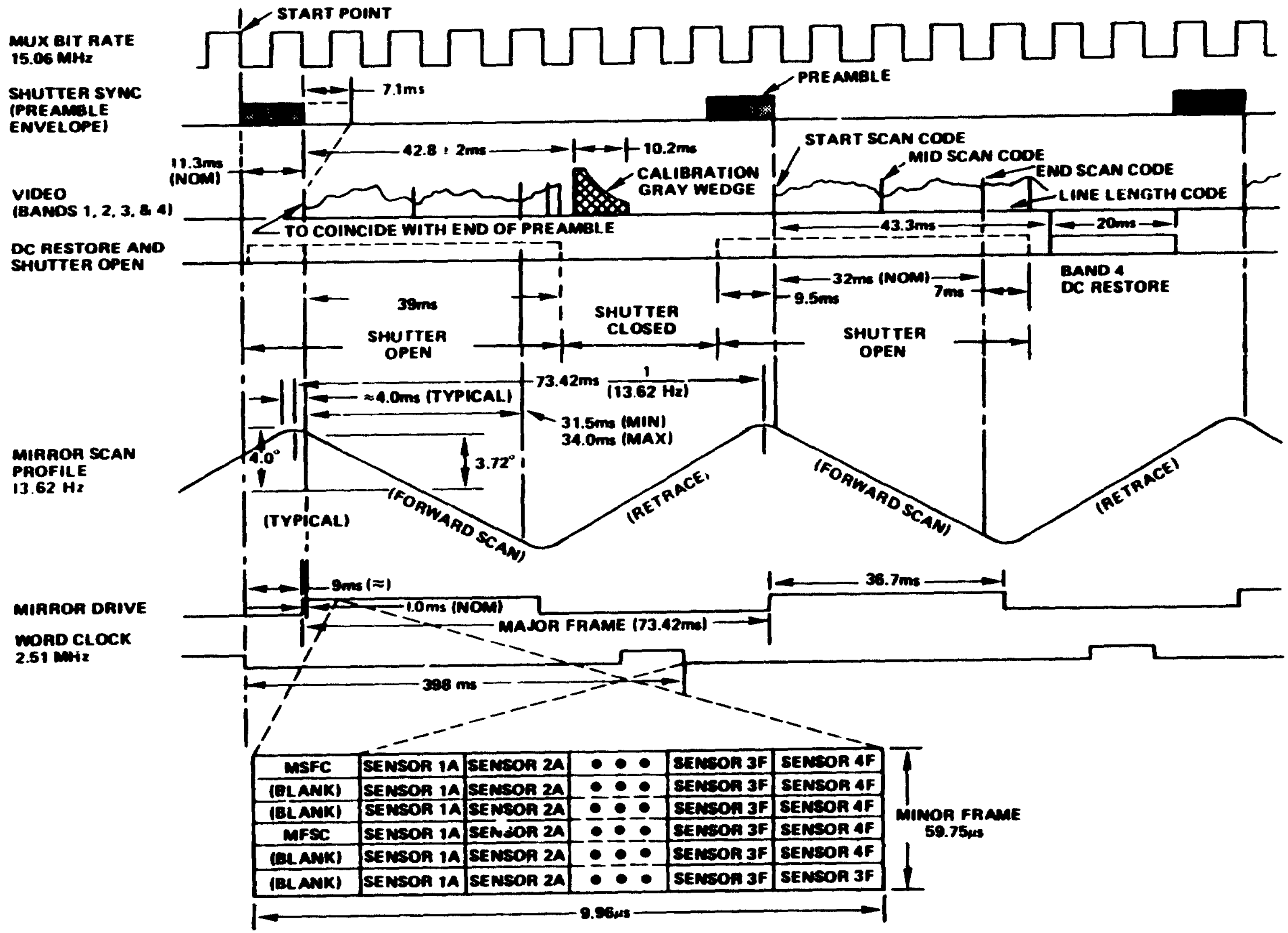

Figure A-2. Multiplexer Data Timing and Format

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Table A-2
Multispectral Scanner Multiplexer and Bit Sync Format

	Coding (6-bit word)	Nominal Time Duration	Nominal Number of Words
Preamble	000111	11.3 ms $\pm$3 ms	28762 $\pm$7503
Start-of-scan code (SMC-1)	111000	0.398 μs	1
Minor-frame sync (MNFS)	001011	0.398 μs	1
Time code	Logic 1's and 0's (110011 and 001100)	19.522 μs	49
Sensor data (video)	Data**	32 ms total	82533
Middle-of-scan code (SMC-M)	100 black* 100 white	79.682 μs	200
End-of-scan code (SMC-2)	100 black* 100 white	79.682 μs	200
Calibration wedge	Data**	10.2 ms	25510
Preamble	Data**	8.871 ms	22186

A2.3 VIDEO DATA

Following the start-of-scan code, the MSS MUX begins to transmit data that are grouped in minor frames of 150 words (i.e., six rows of 25 words each) as shown in Figure A-1. The minor-frame synchronization (MNFS) code is 001011 and occurs as the first word in row 1. The complement of the MNFS occurs as the first word in row 4 of each minor frame. The time-code data from the spacecraft clock are inserted in word positions 2 through 49 of rows 1 and 2 of

*Black 001100, white 110011

**Binary: 0 to 63 levels with center two bits inverted (e.g., level 6 = 001010).

the first minor frame of each scan in place of sensor data as shown in Figures A-3 and A-4. Figure A-4 shows the placement of various units of the BCD time code in different scans. The total code requires that two scans be inserted, and the format alternates back and forth every two scans. Figure A-3 relates the time-code clock output to the MUX-generated envelope and the time-code input to the MUX and shows their relationship within the first minor frame of each scan. Although the spacecraft clock provides a 49-bit NRZ-L time code to the MUX, the 49th bit of the code is not accepted by the MUX, the 49th bit of the code is not accepted by the MUX. Note the time-code envelope in Figure A-3. Also note that spacecraft clock bit 25 is a dummy bit. As for sensor data, a time-code data zero bit is encoded by the MUX as output data bits 001100, and a time-code data one bit as 1100011.

Word positions 2 through 25 in all other rows contain encoded sensor data words from bands 1 through 4. The signal from each band is converted to a binary code in which 000000 represents the least positive voltage levels. After conversion to their binary equivalent, the data are encoded in the MUX by inverting data bits 3 and 4 in each sensor data word (i.e., binary level 0000000 will be encoded as 001100). Sensor data are transmitted with the MSB first.

A2.4 MIDDLE-OF-SCAN CODE

When operated in the midscan indicator ON mode, the MUX pre-empts transmission of sensor data on receipt of the middle-of-scan monitor pulse from the scanner and transmits the middle-of-scan code. Beginning with the word period immediately following the receipt of the pulse, the MUX transmits the encoded equivalent of the black-sensor level (i.e., 0.00 volt input, code 001100) for the next 100-word periods. In the subsequent 100-word periods, the encoded equivalent of the white-sensor level (i.e., 4.0 volts input, code 110011) is transmitted. In the next word period, sensor data resume. (Note that only sensor data are pre-empted; minor frame

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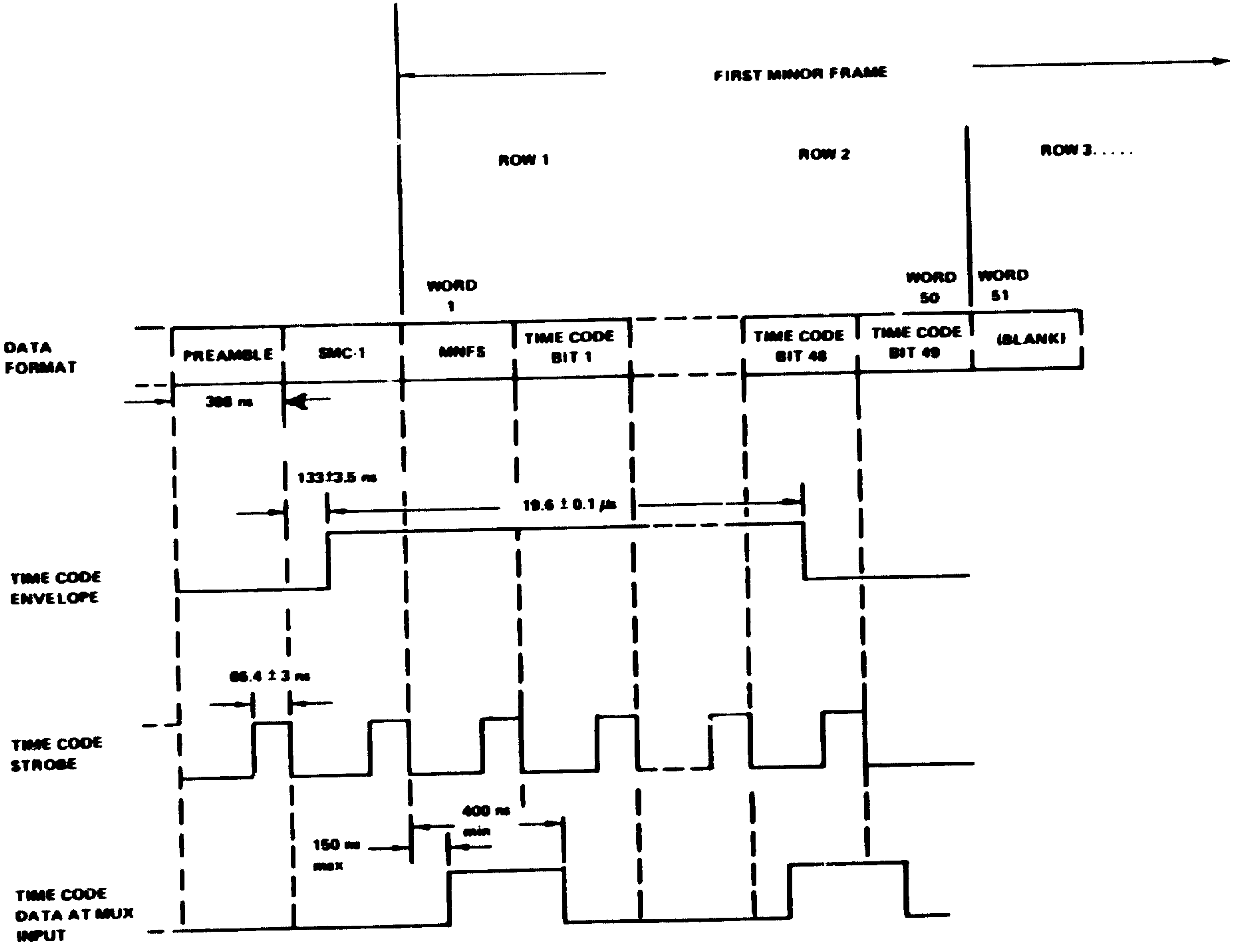
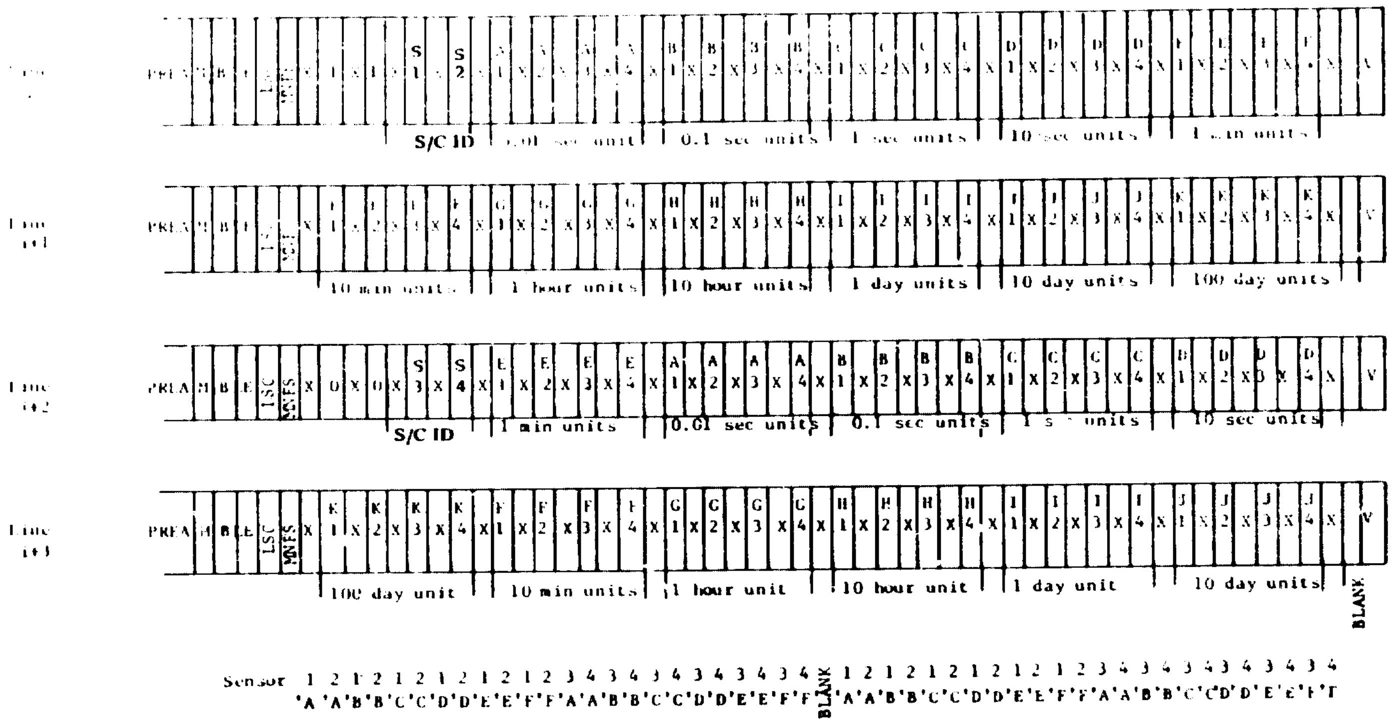


Figure A-3. Relationship of Time-Code Signals to Multiplexer Output



Time-code
update every
i:2n lines
where n = 1,2,3...

Notes:
1. LSB first in time
2. Coding

	0	1
Mux. Internal	000000	111111
Mux. output	001100	110011

3. No data during time code – x
4. Video data – V
5. Line start code – LSC
6. XXXX – spaces
7. S1-S4 = spacecraft ID as follows:
   1110 = Landsat-D
   1101 = Landsat-D'

Notation

A = hundreths of seconds
B = tenths of seconds
C = units seconds
D = tens seconds
E = units minutes
F = tens minutes
G = units hours
H = tens hours
I = units days
J = tens days
K = hundreds days

Figure A-4. MSS Time Code-Format for Landsat-D

synchronization codes are inserted in their proper locations but are included in the count of word periods.) When operated in the mid-scan indicator OFF mode, the MUX ignores the middle-of-scan monitor pulse and continues to transmit sensor data from the scanner. NASA plans to use the midscan code to develop and/or validate mirror v-elocity profiles and mirror scan repeatability. NASA intends to use this mode infrequently on a noninterference basis with foreign acquisition requirements.

A2.5 END-OF-SCAN CODE

On receipt of the end-of-scan monitor pulse from the scanner, the MUX pre-empts transmission of sensor data from the scanner and transmits the end-of-scan code. This code is identical to the black-and-white level code patterns of the middle-of-scan code. After transmission of end-of-scan code (200-word periods), sensor data resume until the end of the major frame.

A2.6 INTERNAL CALIBRATION DATA

Whereas the preceding five subsections cover MUX data output patterns, internal calibration differs in that the MUX does not control it. Calibration data appear in the serial data stream during every other retrace interval (i.e., between the end-of-scan code and the beginning of preamble). During the retrace interval, the scan mirror makes the transmit from east to west, a shutter wheel closes off the optical fiber view to the Earth, and a light source (calibration lamp) is projected onto the fibers through a variable neutral-density filter on the shutter wheel. This process introduces a calibration wedge into the video data stream of bands 1 through 4 during this retrace interval. The nominal shape of the calibration or gray wedge is shown in Figure A-5. The actual shape and level varies somewhat for the detectors in the various spectral bands. The calibration wedge is about 10.2 ms in total duration

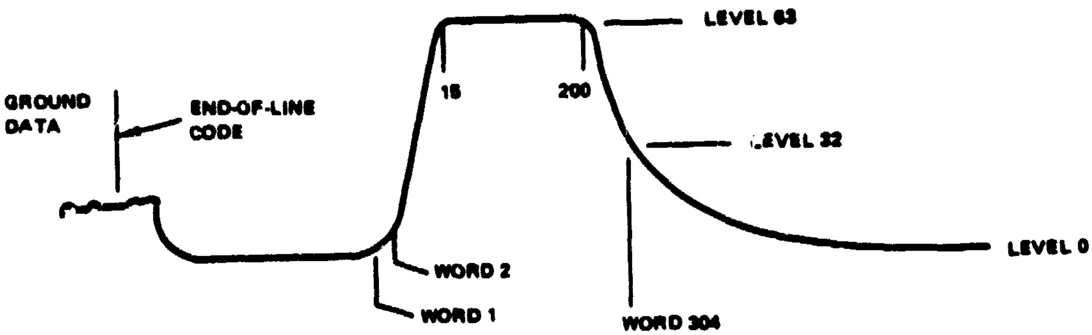


Figure A-5. Nominal Calibration Wedge Curve

wedge density levels (digital) decrease from 63 to 0 and the wedge appears once every 147 ms. Assuming that the calibration lamp intensity is constant, it is possible to obtain a check of the relative radiometric levels and to equalize gain changes that may occur in the six detectors of a spectral band.

Since internal calibration is a function of the rotating shutter and calibration lamp and is not controlled by the MUX, it does not occur at the exact word position in the data stream of every other scan retrace. The purpose of the calibration wedge is to determine that the calibration lamp, neutral-density wedge, optics train, and radiometer visual channels are providing a calibration ramp versus time that can be processed to provide the required number of gray-scale levels of descending half-power levels. Thus, during every other scan retrace, about 10 milliseconds of minor frames contain calibration data in the sensor data words, beginning about 11 ms after end-of-line (noncalibration retraces), the sensors output a black level derived from the detectors looking at a dark surface on the shutter. As with all other sensor data words, the internal calibration data are encoded by inverting the middle two bits. Figure A-6 shows details within the scanner related to internal calibration and band 4 dc restoration.

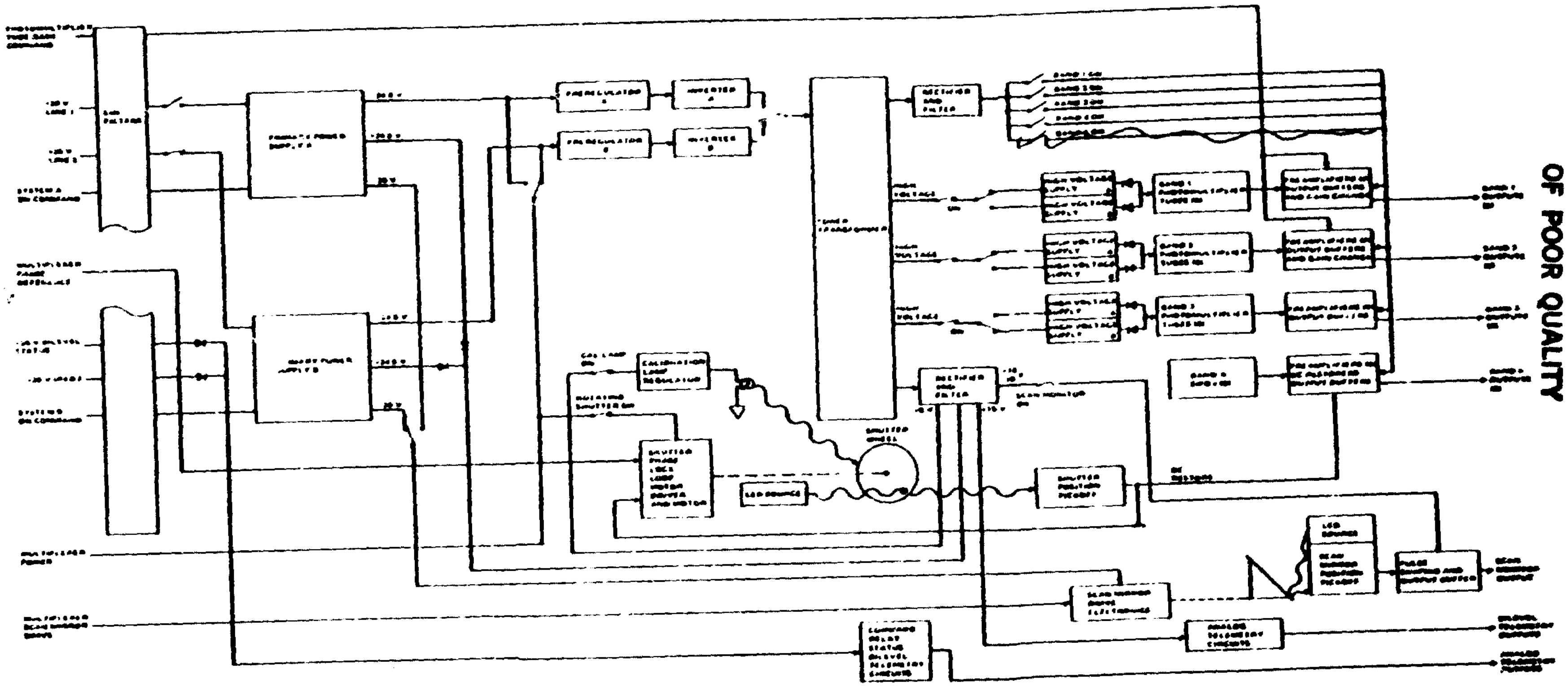


Figure A-6. Scanner Functional Block Diagram

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A3. DEMULTIPLEXER OUTPUT FORMAT

Demultiplexing of the MSS serial data stream takes place within the ground processing system. The DEMUX takes the bit synchronized data stream and recodes all words except minor-frame sync, which remains the same as the MUX output word (001011). The DEMUX generates new words for preamble (010101) and line start (111001) and creates a line-length code (an 18-bit binary word). The DEMUX reinverts the two middle bits for time code, sensor data, midscan code, end-of-line code, and calibration data. Thus, the black level is 000000 instead of 001100.

The DEMUX output format and word codes are shown in Table A-3. Figure A-7 presents a detailed DEMUX output timeline (by word count). Note that this format (Figure A-7 and discussed below) is the same for each of the 24 MSS detectors (i.e., four bands times six detectors per band).

A3.1 PREAMBLE

The preamble lasts for 1319.8 $\pm$20 words and is encoded by the DEMUX as 010101.

A3.2 LINE-START CODE

The line-start code is regenerated by the DEMUX and is 111001.

A3.3 TIME CODE

The first two words after the line-start code are time-code data for the first minor-frame of each mirror scan.

A3.4 SENSOR DATA

Sensor data are binary with the LSB first in levels from 0 (000000) to 63 (111111).

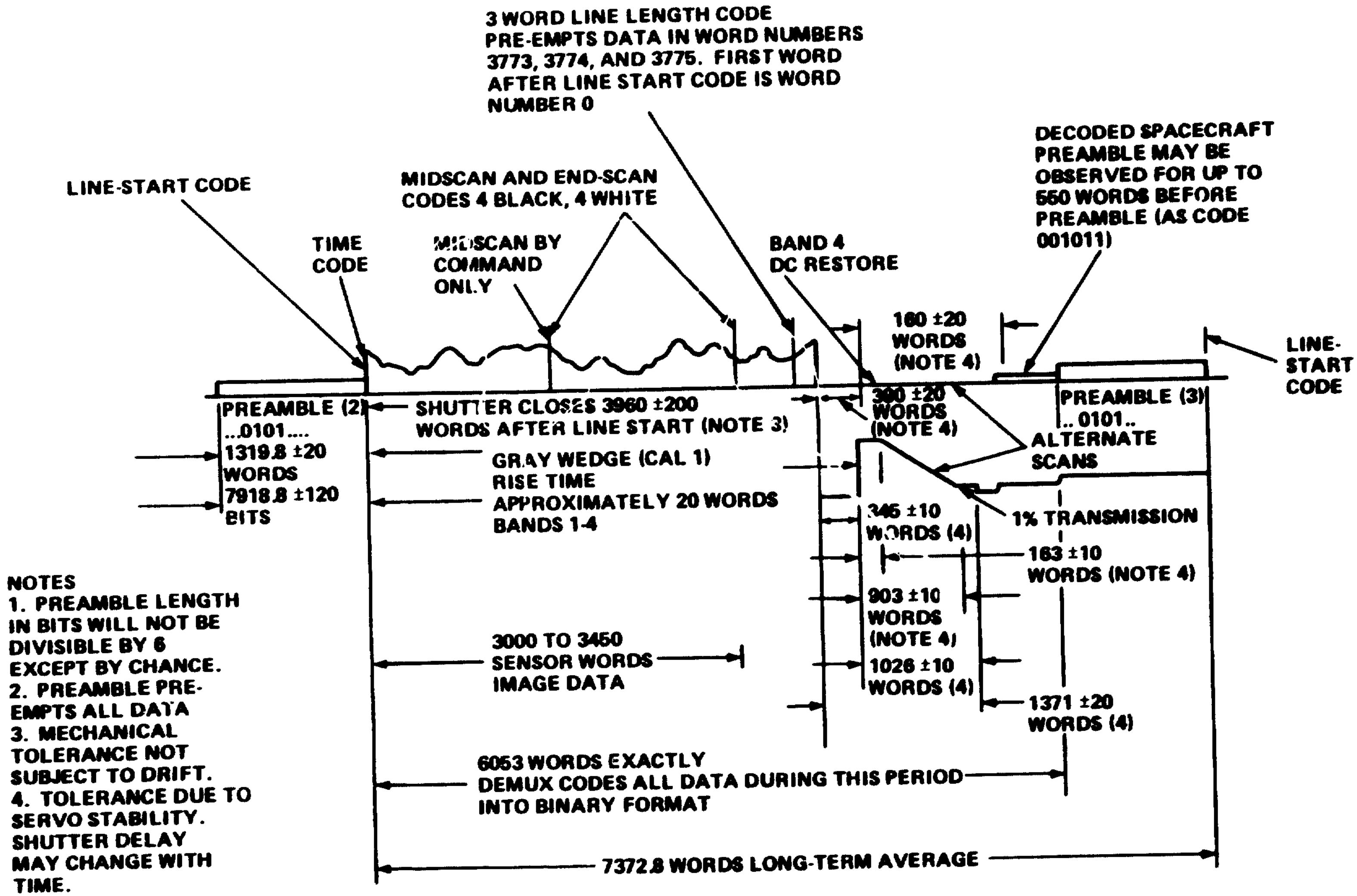

Figure A-7. Demultiplexer Output Format and Timeline

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Table A-3
Demultiplexer Output Format

	Number of 6-Bit Words	Code
Preamble	1313 ±20	010101
Line start	1	111001
Time code	48	Logical 1's and 0's (111111) and (000000)
Sensor data	Maximum range 3000 to 3450**	Binary LSB first
End-of-line code	8	4 x (000000) 4 x (111111)
Line length*	3	Binary LSB first
Calibration 1 (bands 1-4)	(See Figure A-7)	Binary LSB first
Midscan code (by command only)	8	4 x (000000) 4 x (111111)

A3.5 END-OF-LINE CODE

The end-of-line code is recoded by the DEMUX as four black (000000) words and four white (111111) words.

A3.6 LINE-LENGTH CODE

The DEMUX "counts" the total number of words during the sensor data interval, from line start to end-of-line code. The information is put into the data stream at word positions 3773, 3774, and 3775 as in 18-bit binary word with the LSB first. Bits 16, 17, and 18 are always 010, respectively. The number of words in a line for a given

*Occurs at words 3773, 3774, and 3775

**For each of 24 parallel demultiplexed detector data streams.

detector is line length divided by 25. If the DEMUX fails to sync on the end-of-line code, its internal logic will recognize this fact and generate all 1's for words 3773, 3774, and 3775. If the DEMUX fails to synchronize on the line-start pulse, it will continually generate the preamble code until a line start is recognized.

A3.7 CALIBRATION DATA

The calibration data for bands 1 through 4 (Cal 1) are delineated in Figure A-7. The data are sent LSB first. As with sensor data, the center two bits are reinverted by the DEMUX.

A3.8 UNUSED VIDEO DATA

Data words between end-of-line code and shutter closing (except for 18-bit line-length code) represent only shutter-wheel motion and are unused.

APPENDIX B

MSS DATA PROCESSING CONSTANTS

APPENDIX B
MSS DATA PROCESSING CONSTANTS

B1 SPACECRAFT AND SENSOR CONSTANTS

Table B-1 lists the values for certain spacecraft and sensor constants required in ground processing. The MSS band-to-band offsets are given for Bands 2, 3 and 4 with an implied zero for Band 1. The offset is a number such that when added to a "sampling time delay" for a detector of that band, the result is an offset in pixels for that detector from a fictitious detector for which the resampling matrices were formed. Thus 27 numbers are given: 3 "band-to-band" offsets and 24 "sampling time" delays. (A set of six is repeated for each band.) This particular partition was selected to satisfy certain historically acceptable formats. Decompression data are provided in Table B-2.

Table B-1
Spacecraft and Sensor Constants

Data Description	Values
Nominal number of pixels per input line	3240
Number of input lines in the partially processed image	2400
Nominal scale of input interpixel distance in meters per pixel	57
Nominal scale of input interline distance in meters per pixel	82.7
Number of pixels per output line of fully processed image	3548
Number of lines per output image of fully processed image	2983
Scale of fully processed output interpixel distance in meters per pixel	57
Scale of fully processeed output interline distance in meters per pixel	57

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Table B-1 (Continued)

Data Description	Values
Nominal spacecraft altitude in meters	705300
Nominal input swath width in meters	185000
The prelaunch mirror scan profile for MSS is of the following form:	
$\ell = 2 \cdot A \cdot e^{-\beta\ 2-1) t_s} \cdot \sin W\ (t_0 + \{i - 13\}\ t_s)$	
with	
ℓ = scan angle, rad.	
A = harmonic amplitude	0.23387 rad
β = damping constant	0.00739/sec
i = pixel number	$1 \leq i \leq$ linelength
t_s = sampling time	9.958 μsec
W = mirror frequency	17.499
t_0 = start time for scan relative to center pixel time	-16.15 ms
MSS maximum mirror angle in radians	0.260
Scan skew constant in radians	0.00135135
Time between successive MSS mirror sweeps in seconds	0.07342
Time for the active portion of an MSS mirror sweep in seconds	0.03230
Semimajor axis of Earth ellipsoid (International Spheroid) in meters	6378388
Semiminor axis of Earth ellipsoid (International Spheroid) in meters	6356912
Earth curvature constant in meters^{-2}	1.113315×10^{-13}
MSS sampling delay consists (24 values, one for each detector) measured in input image along-scan pixel units. The MSS sampling delay constants will appear in the following order:	

Table B-1 (Continued)

Data Description	Values
Band 1 detector 1	-2.720805
detector 2	-2.800665
detector 3	-2.880525
detector 4	-2.960385
detector 5	-3.040245
detector 6	-3.120105
Band 2 detector 1-6 Band 3 detector 1-6 Band 4 detector 1-6 } Same values as for Band 1 detectors 1-6, respectively	
MSS band-to-band offsets with respect to band 1 (3 values: one each for bands 2, 3 and 4) measured in input image along-scan pixel units	Band 2 = 1.95007 Band 3 = 3.89084 Band 4 = 5.84091

Table B-2
Landsat-D MSS Decompression Table

Compressed Quantum Level	Equivalent Linear Quantum Level		Compressed Quantum Level	Equivalent Linear Quantum Level	
	Bands 1&3	Band 2		Bands 1&3	Band 2
0	0	0	32	42	42
1	1	1	33	44	44
2	2	2	34	46	46
3	3	2	35	48	48
4	3	3	36	50	49
5	4	4	37	52	51
6	5	5	38	54	54
7	6	6	39	56	56
8	7	7	40	59	59
9	8	8	41	62	61
10	9	9	42	65	64
11	10	10	43	67	67
12	11	11	44	70	70
13	12	12	45	73	73
14	13	13	46	76	76
15	14	14	47	79	79
16	16	16	48	82	81
17	17	17	49	85	84
18	18	18	50	88	87
19	20	19	51	91	90
20	21	21	52	94	93
21	22	22	53	96	96
22	24	24	54	99	99
23	26	26	55	102	102
24	27	27	56	105	105
25	29	29	57	108	108
26	31	31	58	111	111
27	33	33	59	114	114
28	34	34	60	117	117
29	36	36	61	120	120
30	38	38	62	123	123
31	40	40	63	127	127

B2 CALIBRATION WEDGE WORD COUNT VALUES

Table B-3 presents the number of pixels from the mid-point of the calibration wedge leading edge to the point at which each of six values are to be extracted for use in gain and offset calculations. Separate table segments are provided for each mode of sensor operation (high gain/low gain, use of prime/redundant calibration source lamp). Within each segment, sets of six word count values are provided for each band; and each set applies to all detectors within the band.

B3 NOMINAL CALBRATION QUANTUM LEVEL VALUES

Table B-4 presents the nominal digital values that can be expected at each calibration wedge location defined in Table B-3. Separate table segments are provided for each combination of sensor mode (high/low gain, use of prime/redundant calibration source lamp) and signal amplifier mode (linear/compressed). Within each segment, radiance values are provided for each word count value of each detector.

B4 OFFSET AND GAIN COEFFICIENTS (C_i and D_i Values)

Tables B-5, B-6, B-7 and B-8 present the regression coefficients used with calibration wedge radiance values (which are extracted at locations defined by Table B-3) to calculate the gain and offset values that describe the radiance calibration function for each detector. Each table describes a mode of sensor operation (high/low gain, use of prime/redundant calibration source lamp). Within each table, separate segments are provided for each detector of each band. Each segment contains an offset coefficient value and a gain coefficient value for each of the six calibration quantum level values to be extracted from the calibration wedge portion of the MSS data.

It should be noted that no multiplicative or additive modified values (M's and A's) have been developed to further adjust the radiometric calibration functions defined by the data provided in Tables B-3 through B-8; that is, the nominal values of M = 1.0 and A = 0.0 apply to all detectors.

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Table B-3
Calibration Wedge Word Count Values

	Calibration Wedge Word Count* For Locating Sample Number:					
● Lamp A (Prime)						
High Gain:	1	2	3	4	5	6
Band 1	470	480	490	500	920	930
Band 2	580	590	600	610	950	960
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
Low Gain:						
Band 1	230	240	250	260	810	820
Band 2	340	350	360	370	880	890
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
● Lamp B (Redundant)						
High Gain:						
Band 1	470	480	490	500	920	930
Band 2	580	590	600	610	950	960
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760
Low Gain:						
Band 1	230	240	250	260	810	820
Band 2	340	350	360	370	880	890
Band 3	380	390	400	410	890	900
Band 4	330	340	350	360	750	760

* Number of pixels (words), counting from the mid-point of the leading edge of the cal. wedge, to the location of each of the six word samples to be extracted from the wedge.

Table B-4
Nominal Calibration Record

1st Detector of Band: 1st Word Count					Last Word Count	2nd Detector of Band: 1st Word Count					Last Word Count	3rd Detector of Band: 1st Word Count					Last Word Count	4th Detector of Band: 1st Word Count					Last Word Count	5th Detector of Band: 1st Word Count					Last Word Count	6th Detector of Band: 1st Word Count					Last Word Count	
ACTIVE DETECTOR STATUS: AAAAAAAAAAAAAAAAAAAAAA																																				
CAL WEDGE (HIGH GAIN,LINEAR,LAMP A)																																				
44	42	40	38	2	2	45	42	40	38	2	2	46	44	42	40	2	2	45	42	41	40	2	2	44	42	40	38	2	2	45	44	41	40	2	2	Band 1
42	40	36	34	2	1	45	42	40	37	2	1	38	35	33	31	1	1	40	37	35	33	2	1	41	39	36	34	2	1	42	37	37	35	2	1	Band 2
45	43	40	38	3	3	46	43	41	39	3	3	47	45	43	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	38	3	2	Band 3
52	48	46	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (LOW GAIN,LINEAR,LAMP A)																																				
50	47	45	43	2	2	50	47	45	43	2	2	52	49	47	46	2	2	51	48	45	43	2	2	49	46	44	42	2	2	50	48	45	43	2	2	Band 1
50	47	44	42	2	2	54	50	48	45	2	2	46	43	41	39	2	2	48	45	42	40	2	2	50	47	45	42	2	2	51	48	45	43	2	2	Band 2
45	43	40	38	3	3	46	43	41	39	3	3	47	45	43	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	38	3	2	Band 3
52	48	46	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (HIGH GAIN,COMPRESSED,LAMP A)																																				
50	49	47	46	5	4	51	49	47	46	6	4	52	50	49	47	6	4	51	49	48	47	5	4	50	49	47	46	5	4	51	50	48	47	6	4	Band 1
49	47	45	44	5	3	51	49	47	46	5	3	46	44	43	41	4	3	48	46	44	43	5	4	49	47	45	44	5	4	49	47	46	44	5	4	Band 2
51	49	48	46	7	6	52	50	48	47	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	48	46	6	6	51	50	48	46	7	6	Band 3
52	48	46	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (LOW GAIN,COMPRESSED,LAMP A)																																				
54	53	51	49	5	5	54	53	51	49	5	5	56	54	52	51	5	5	55	53	51	50	5	5	54	52	50	49	5	5	55	53	51	50	5	5	Band 1
55	53	51	49	6	5	57	55	53	51	6	5	52	50	49	47	5	5	53	51	49	48	6	5	55	53	51	49	6	6	55	53	51	50	6	6	Band 2
51	49	48	46	7	6	52	50	48	47	7	6	53	51	49	46	7	7	51	49	48	46	7	6	51	49	48	46	6	5	51	50	48	46	7	6	Band 3
52	48	46	42	5	5	50	47	44	41	5	5	53	50	47	44	5	5	49	46	43	40	5	4	45	42	39	37	4	4	46	43	40	38	4	4	Band 4
CAL WEDGE (HIGH GAIN,LINEAR,LAMP B)																																				
46	43	41	39	3	2	46	43	41	39	3	2	47	45	43	41	3	2	46	44	42	39	3	2	45	43	41	39	3	2	47	44	42	40	3	2	Band 1
44	41	40	38	4	4	47	44	42	40	4	4	39	37	36	34	4	3	42	40	38	36	4	4	44	42	40	38	4	4	46	43	41	39	4	4	Band 2
45	42	40	38	3	3	45	42	40	38	3	3	47	45	42	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	39	3	2	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (LOW GAIN,LINEAR,LAMP B)																																				
51	48	46	44	2	2	51	48	46	43	2	2	53	50	47	45	2	2	52	49	47	45	2	2	50	48	45	43	2	2	52	49	47	45	2	2	Band 1
50	47	45	42	2	2	53	51	48	45	3	2	46	43	41	39	2	2	48	46	43	40	2	2	51	49	46	43	3	2	53	50	47	45	3	2	Band 2
45	42	40	38	3	3	45	42	40	38	3	3	47	45	42	40	3	3	45	42	40	38	3	3	45	42	40	38	3	2	46	43	41	39	3	2	Band 3
44	41	39	37	4	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (HIGH GAIN,COMPRESSED,LAMP B)																																				
51	50	48	47	6	6	51	50	48	47	7	6	53	51	50	48	7	6	52	50	49	47	7	6	51	50	48	47	6	6	52	51	49	47	7	6	Band 1
51	49	47	46	9	9	52	51	49	48	9	9	47	46	45	43	8	8	49	48	46	45	9	9	51	49	48	46	10	9	52	50	48	47	10	9	Band 2
51	49	48	46	7	6	51	49	48	46	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	47	46	6	5	52	50	48	47	6	6	Band 3
44	41	39	37	6	4	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4
CAL WEDGE (LOW GAIN,COMPRESSED,LAMP B)																																				
55	53	52	50	5	5	55	53	51	50	5	5	57	55	53	51	6	2	56	54	52	51	5	2	55	53	51	50	5	5	56	54	52	51	6	5	Band 1
55	53	51	49	5	5	57	55	53	51	6	5	52	50	49	47	5	5	53	52	50	48	6	5	55	56	52	50	7	6	56	55	53	51	7	6	Band 2
51	49	48	46	7	6	51	49	48	46	7	6	53	51	49	48	7	7	51	49	48	46	7	6	51	49	47	46	6	5	52	50	48	47	6	6	Band 3
44	41	39	37	4	[illegible]	44	42	39	37	4	4	50	47	44	41	4	4	45	42	40	38	4	4	40	38	36	33	4	3	40	38	36	34	4	3	Band 4

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Table B-5

Lamp A (Prime) - High Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5034660E-01	-0.2014560E-01	0.9569900E-02	0.3634670E-01	0.5090237	0.5155502	Band 1
	GAINS:	0.4393915	0.3732430	0.3180776	0.2638818	-0.6931777	-0.7073921	
DETECTOR 2	OFFSETS:	-0.4696410E-01	-0.1757830E-01	0.1402540E-01	0.3933830E-01	0.5018356	0.5093431	
	GAINS:	0.4459089	0.3845716	0.3186063	0.2657748	-0.6995937	-0.7152642	
DETECTOR 3	OFFSETS:	-0.4951040E-01	-0.2031060E-01	0.9781000E-02	0.3498490E-01	0.5089316	0.5141420	
	GAINS:	0.4415793	0.3819324	0.3205073	0.2608120	-0.6950566	-0.7097797	
DETECTOR 4	OFFSETS:	-0.4863200E-01	-0.1837630E-01	0.1187500E-01	0.3824920E-01	0.5049975	0.5120457	
	GAINS:	0.4504787	0.3871738	0.3242962	0.2686938	-0.7079045	-0.7227359	
DETECTOR 5	OFFSETS:	-0.4772620E-01	-0.1728000E-01	0.1305800E-01	0.3843440E-01	0.5031191	0.5133938	
	GAINS:	0.4419056	0.3791494	0.3186170	0.2643118	-0.6934940	-0.7068888	
DETECTOR 6	OFFSETS:	-0.4818700E-01	-0.1804520E-01	0.1234110E-01	0.3968050E-01	0.5031267	0.5110831	
	GAINS:	0.4475009	0.3847212	0.3214320	0.2644894	-0.7007848	-0.7173566	
DETECTOR 7	OFFSETS:	-0.4978410E-01	-0.1379920E-01	0.2319780E-01	0.5015780E-01	0.4914715	0.4987552	Band 2
	GAINS:	0.4471573	0.3728172	0.2563865	0.2408913	-0.6710020	-0.6860487	
DETECTOR 8	OFFSETS:	-0.4786690E-01	-0.5499200E-02	0.2722290E-01	0.4989290E-01	0.4850060	0.4918417	
	GAINS:	0.4527251	0.3633089	0.2942579	0.2468412	-0.6717733	-0.6853501	
DETECTOR 9	OFFSETS:	-0.4764340E-01	-0.6085000E-02	0.3098510E-01	0.5721700E-01	0.4803672	0.4851587	
	GAINS:	0.4620484	0.3724492	0.2925267	0.2359710	-0.6763325	-0.6860824	
DETECTOR 10	OFFSETS:	-0.4595430E-01	-0.1156960E-01	0.2572820E-01	0.5119340E-01	0.4871823	0.4938390	
	GAINS:	0.4537220	0.3803466	0.3007549	0.2464136	-0.6839200	-0.6973141	
DETECTOR 11	OFFSETS:	-0.4826260E-01	-0.1290520E-01	0.2150040E-01	0.4753510E-01	0.4926770	0.4994534	
	GAINS:	0.4394034	0.3671185	0.2967794	0.2435538	-0.6866986	-0.6803529	
DETECTOR 12	OFFSETS:	-0.4813160E-01	-0.9664100E-02	0.2116110E-01	0.4747760E-01	0.4910113	0.4981651	
	GAINS:	0.4532148	0.3720571	0.3070097	0.2514838	-0.6841521	-0.6994866	
DETECTOR 13	OFFSETS:	-0.5704220E-01	-0.2197540E-01	0.8423000E-02	0.3960200E-01	0.5132497	0.5177433	Band 3
	GAINS:	0.4055327	0.3419847	0.2866595	0.2303389	-0.6282750	-0.6364208	
DETECTOR 14	OFFSETS:	-0.5796830E-01	-0.2231510E-01	0.8275200E-02	0.3914950E-01	0.5141711	0.5188867	
	GAINS:	0.4074529	0.3427829	0.2872969	0.2312958	-0.6303183	-0.6385089	
DETECTOR 15	OFFSETS:	-0.5926110E-01	-0.2706710E-01	0.4115500E-02	0.3753270E-01	0.5200883	0.5246107	
	GAINS:	0.4143347	0.3552930	0.2981060	0.2308220	-0.6481126	-0.6508431	
DETECTOR 16	OFFSETS:	-0.6022840E-01	-0.2476510E-01	0.7526200E-02	0.3820340E-01	0.5173103	0.5218927	
	GAINS:	0.4272965	0.3605108	0.2998986	0.2418133	-0.6603447	-0.6689765	
DETECTOR 17	OFFSETS:	-0.5673130E-01	-0.2233320E-01	0.8034400E-02	0.3840470E-01	0.5149243	0.5196952	
	GAINS:	0.4306794	0.3611317	0.3031066	0.2450889	-0.6654352	-0.6745509	
DETECTOR 18	OFFSETS:	-0.5866450E-01	-0.2347670E-01	0.8840600E-02	0.3874310E-01	0.5149391	0.5198175	
	GAINS:	0.4225129	0.3565332	0.2959358	0.2398889	-0.6530377	-0.6618182	
DETECTOR 19	OFFSETS:	-0.8950200E-01	-0.4144800E-01	-0.3951700E-02	0.3990730E-01	0.5467716	0.5482212	Band 4
	GAINS:	0.4161379	0.3380703	0.2771686	0.2059172	-0.6174682	-0.6198230	
DETECTOR 20	OFFSETS:	-0.8913090E-01	-0.4259440E-01	-0.2070100E-02	0.3881090E-01	0.5463896	0.5485971	
	GAINS:	0.4322807	0.3536371	0.2851537	0.2100678	-0.6417043	-0.6454380	
DETECTOR 21	OFFSETS:	-0.8683630E-01	-0.3995820E-01	-0.1136500E-02	0.3891870E-01	0.5437302	0.5452751	
	GAINS:	0.4192705	0.3417387	0.2775145	0.2112885	-0.6236283	-0.6261835	
DETECTOR 22	OFFSETS:	-0.8828550E-01	-0.4554920E-01	-0.2763300E-02	0.4068930E-01	0.5471393	0.5488122	
	GAINS:	0.4478498	0.3727788	0.2976214	0.2213827	-0.6863377	-0.6712764	
DETECTOR 23	OFFSETS:	-0.8513990E-01	-0.4298810E-01	-0.7428000E-03	0.3921280E-01	0.5441099	0.5455478	
	GAINS:	0.4754781	0.3958642	0.3161137	0.2406665	-0.7127149	-0.7154362	
DETECTOR 24	OFFSETS:	-0.8418970E-01	-0.4236670E-01	-0.3248000E-03	0.3645530E-01	0.5442715	0.5461547	
	GAINS:	0.4599492	0.3832689	0.3061812	0.2387447	-0.6923453	-0.6957984	

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Table B-6
Lamp A (Prime) - Low Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5044050E-01	-0.2074160E-01	0.8467600E-02	0.3403190E-01	0.5137314	0.5149515	Band 1
	GAINS:	0.4066399	0.3510138	0.2963050	0.2484233	-0.6500483	-0.6523336	
DETECTOR 2	OFFSETS:	-0.4896130E-01	-0.1938700E-01	0.7744700E-02	0.3452540E-01	0.5123792	0.5136988	
	GAINS:	0.4174407	0.3601867	0.3076617	0.2558161	-0.6692752	-0.6718259	
DETECTOR 3	OFFSETS:	-0.4889510E-01	-0.1909270E-01	0.7016700E-02	0.3240320E-01	0.5135559	0.5150127	
	GAINS:	0.4083158	0.3518636	0.3024074	0.2543206	-0.6570740	-0.6598334	
DETECTOR 4	OFFSETS:	-0.4896040E-01	-0.1941010E-01	0.7365400E-02	0.3306180E-01	0.5131426	0.5148601	
	GAINS:	0.4205451	0.3629122	0.3108079	0.2605765	-0.6757452	-0.6790944	
DETECTOR 5	OFFSETS:	-0.4955080E-01	-0.2222870E-01	0.9532700E-02	0.3481040E-01	0.5126950	0.5147414	
	GAINS:	0.4177801	0.3649877	0.3036175	0.2547755	-0.6686032	-0.6725572	
DETECTOR 6	OFFSETS:	-0.4973960E-01	-0.1888300E-01	0.7961100E-02	0.3248870E-01	0.5132293	0.5149455	
	GAINS:	0.4202252	0.3603066	0.3081800	0.2605554	-0.6729670	-0.6762957	
DETECTOR 7	OFFSETS:	-0.5544900E-01	-0.1940160E-01	0.1182860E-01	0.4251390E-01	0.5086271	0.5118808	Band 2
	GAINS:	0.3761566	0.3151097	0.2622208	0.2102847	-0.5791156	-0.5840258	
DETECTOR 8	OFFSETS:	-0.5463910E-01	-0.1916970E-01	0.1063320E-01	0.3967680E-01	0.5098675	0.5134305	
	GAINS:	0.3768380	0.3167271	0.2659329	0.2164330	-0.5843292	-0.5910016	
DETECTOR 9	OFFSETS:	-0.5335200E-01	-0.1617020E-01	0.1165940E-01	0.3808120E-01	0.5090845	0.5121167	
	GAINS:	0.3771513	0.3168435	0.2657101	0.2194242	-0.5869656	-0.5921633	
DETECTOR 10	OFFSETS:	-0.5441640E-01	-0.1823660E-01	0.1291340E-01	0.4082070E-01	0.5080326	0.5108856	
	GAINS:	0.3847621	0.3217964	0.2675844	0.2190160	-0.5940966	-0.5990620	
DETECTOR 11	OFFSETS:	-0.5380060E-01	-0.1977140E-01	0.1027140E-01	0.4085980E-01	0.5098633	0.5129766	
	GAINS:	0.3696881	0.3126266	0.2622496	0.2109577	-0.5746152	-0.5807067	
DETECTOR 12	OFFSETS:	-0.5412580E-01	-0.1990290E-01	0.9926100E-02	0.4152150E-01	0.5094231	0.5131574	
	GAINS:	0.3807511	0.3217345	0.2702951	0.2158098	-0.5910753	-0.5975146	
DETECTOR 13	OFFSETS:	-0.5704220E-01	-0.2197540E-01	0.8423000E-02	0.3960200E-01	0.5132497	0.5177433	Band 3
	GAINS:	0.4055327	0.3419647	0.2868595	0.2303389	-0.6282750	-0.6306208	
DETECTOR 14	OFFSETS:	-0.5796830E-01	-0.2231510E-01	0.8275200E-02	0.3914950E-01	0.5141711	0.5188887	
	GAINS:	0.4074523	0.3427829	0.2872569	0.2312458	-0.6303183	-0.6385089	
DETECTOR 15	OFFSETS:	-0.5926110E-01	-0.2706710E-01	0.4115500E-02	0.3753270E-01	0.5200883	0.5268107	
	GAINS:	0.4143347	0.3552930	0.2981066	0.2368220	-0.6481126	-0.6566431	
DETECTOR 16	OFFSETS:	-0.6023284E-01	-0.2476510E-01	0.7526200E-02	0.3628340E-01	0.5173103	0.5218927	
	GAINS:	0.4272965	0.3605108	0.2996986	0.2418133	-0.6603447	-0.6689745	
DETECTOR 17	OFFSETS:	-0.5873130E-01	-0.2233320E-01	0.8034400E-02	0.3840870E-01	0.5149243	0.5196952	
	GAINS:	0.4306794	0.3611317	0.3031066	0.2450689	-0.6654352	-0.6745509	
DETECTOR 18	OFFSETS:	-0.5866450E-01	-0.2347670E-01	0.8406000E-02	0.3874310E-01	0.5149391	0.5198175	
	GAINS:	0.4225129	0.3565332	0.2959356	0.2398884	-0.6530377	-0.6618102	
DETECTOR 19	OFFSETS:	-0.8950200E-01	-0.4144460E-01	-0.3951700E-02	0.3990730E-01	0.5467716	0.5482212	Band 4
	GAINS:	0.4161379	0.3380703	0.2771846	0.2059172	-0.6174682	-0.6198230	
DETECTOR 20	OFFSETS:	-0.8913090E-01	-0.4259440E-01	-0.2070100E-02	0.3881090E-01	0.5463896	0.5485971	
	GAINS:	0.4322807	0.3536371	0.2851537	0.2100676	-0.6417043	-0.6454350	
DETECTOR 21	OFFSETS:	-0.8683630E-01	-0.3595620E-01	-0.1126500E-02	0.3891870E-01	0.5437302	0.5452751	
	GAINS:	0.4192705	0.3417387	0.2775145	0.2112865	-0.6236263	-0.6261635	
DETECTOR 22	OFFSETS:	-0.8828550E-01	-0.4554920E-01	-0.2763300E-02	0.4064930E-01	0.5471393	0.5488122	
	GAINS:	0.4478498	0.3727786	0.2976214	0.2213627	-0.6683377	-0.6712764	
DETECTOR 23	OFFSETS:	-0.8513990E-01	-0.4298810E-01	-0.7428000E-03	0.3921480E-01	0.5441099	0.5455478	
	GAINS:	0.4754781	0.3958842	0.3161137	0.2406665	-0.7127149	-0.7158302	
DETECTOR 24	OFFSETS:	-0.8418970E-01	-0.4236670E-01	-0.3246000E-03	0.3845530E-01	0.5442715	0.5461567	
	GAINS:	0.4599492	0.3832669	0.3061812	0.2387467	-0.6923453	-0.6957988	

Table B-7

Lamp B (Prime) - High Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5383770E-01	-0.2314010E-01	0.6896000E-02	0.3447840E-01	0.5152776	0.5203240	Band 1
	GAINS:	0.4306146	0.3706659	0.3120100	0.2581455	-0.6807473	-0.6906456	
DETECTOR 2	OFFSETS:	-0.5131310E-01	-0.2134540E-01	0.8583100E-02	0.3678250E-01	0.5111665	0.5161244	
	GAINS:	0.4441122	0.3830557	0.3220796	0.2646204	-0.7018843	-0.7119856	
DETECTOR 3	OFFSETS:	-0.5204000E-01	-0.2547210E-01	0.4418200E-02	0.3538790E-01	0.5161735	0.5215313	
	GAINS:	0.4359769	0.3830154	0.3234310	0.2610950	-0.6967177	-0.7073981	
DETECTOR 4	OFFSETS:	-0.5517190E-01	-0.2453140E-01	0.5966900E-02	0.3561150E-01	0.5164109	0.5217128	
	GAINS:	0.4524348	0.3899441	0.3277441	0.2672845	-0.7132953	-0.7241084	
DETECTOR 5	OFFSETS:	-0.5234010E-01	-0.2212130E-01	0.9521300E-02	0.3583130E-01	0.5118428	0.5172654	
	GAINS:	0.4387688	0.3782274	0.3148327	0.2621215	-0.6915425	-0.7024066	
DETECTOR 6	OFFSETS:	-0.5273780E-01	-0.2348360E-01	0.6308200E-02	0.3697390E-01	0.5138791	0.5190389	
	GAINS:	0.4451463	0.3857524	0.3253493	0.2631319	-0.7084545	-0.7149233	
DETECTOR 7	OFFSETS:	-0.6073620E-01	-0.2271010E-01	0.3033300E-02	0.2605410E-01	0.5262825	0.5280746	Band 2
	GAINS:	0.4285845	0.3569165	0.3083981	0.2650113	-0.6777646	-0.6811422	
DETECTOR 8	OFFSETS:	-0.5987640E-01	-0.2461550E-01	0.5069000E-02	0.3174230E-01	0.5226335	0.5248264	
	GAINS:	0.4380113	0.3698357	0.3124033	0.2608706	-0.6886329	-0.6924859	
DETECTOR 9	OFFSETS:	-0.5640410E-01	-0.2536150E-01	0.4667900E-02	0.3321290E-01	0.5210618	0.5228211	
	GAINS:	0.4360635	0.3753809	0.3186786	0.2608761	-0.6927794	-0.6962186	
DETECTOR 10	OFFSETS:	-0.5449460E-01	-0.2156940E-01	0.4883000E-03	0.2955910E-01	0.5222649	0.5237499	
	GAINS:	0.4286624	0.3648455	0.3221315	0.2657467	-0.6892716	-0.6921114	
DETECTOR 11	OFFSETS:	-0.6550580E-01	-0.2730500E-01	0.6767000E-03	0.2320630E-01	0.5333157	0.5358111	
	GAINS:	0.4249166	0.3556025	0.3037907	0.2625574	-0.6710319	-0.6752328	
DETECTOR 12	OFFSETS:	-0.6302850E-01	-0.2749620E-01	0.3275500E-02	0.2745940E-01	0.5290809	0.5307344	
	GAINS:	0.4364259	0.3638469	0.3061761	0.2608597	-0.6791260	-0.6821758	
DETECTOR 13	OFFSETS:	-0.5633750E-01	-0.2146400E-01	0.9054400E-02	0.3930820E-01	0.5128416	0.5165965	Band 3
	GAINS:	0.4018272	0.3389892	0.2839987	0.2294848	-0.6237667	-0.6305326	
DETECTOR 14	OFFSETS:	-0.5565900E-01	-0.2301500E-01	0.9313500E-02	0.3859700E-01	0.5137771	0.5169862	
	GAINS:	0.4104207	0.3501585	0.2904791	0.2364209	-0.6407773	-0.6467015	
DETECTOR 15	OFFSETS:	-0.5909790E-01	-0.2957550E-01	0.2990700E-02	0.3609760E-01	0.5230393	0.5265452	
	GAINS:	0.4111196	0.3573549	0.2980555	0.2377676	-0.6489566	-0.6553429	
DETECTOR 16	OFFSETS:	-0.5890460E-01	-0.2356640E-01	0.8523200E-02	0.3598600E-01	0.5172936	0.5208882	
	GAINS:	0.4195329	0.3538085	0.2941260	0.2430488	-0.6521198	-0.6583981	
DETECTOR 17	OFFSETS:	-0.5729180E-01	-0.2311620E-01	0.1103720E-01	0.3762870E-01	0.5140637	0.5176793	
	GAINS:	0.4250826	0.3602161	0.2953913	0.2449197	-0.6593733	-0.6662356	
DETECTOR 18	OFFSETS:	-0.5744090E-01	-0.2188710E-01	0.9675900E-02	0.3629170E-01	0.5134956	0.5172843	
	GAINS:	0.4148560	0.3488704	0.2906130	0.2378407	-0.6427722	-0.6498080	
DETECTOR 19	OFFSETS:	-0.7643870E-01	-0.3634200E-01	-0.1703500E-02	0.3293920E-01	0.5399743	0.5415704	Band 4
	GAINS:	0.4644912	0.3878804	0.3216975	0.2555075	-0.7132646	-0.7163138	
DETECTOR 20	OFFSETS:	-0.7675450E-01	-0.3728760E-01	-0.2027100E-02	0.3228370E-01	0.5409477	0.5428379	
	GAINS:	0.4657200	0.3902111	0.3227499	0.2571054	-0.7160860	-0.7197023	
DETECTOR 21	OFFSETS:	-0.7632510E-01	-0.3855000E-01	-0.1967000E-02	0.3442040E-01	0.5398450	0.5425705	
	GAINS:	0.4301274	0.3632604	0.2965036	0.2340937	-0.6605760	-0.6654124	
DETECTOR 22	OFFSETS:	-0.7966350E-01	-0.3861690E-01	-0.3831400E-02	0.3020800E-01	0.5452149	0.5466886	
	GAINS:	0.4643362	0.3869625	0.3213909	0.2572265	-0.7135698	-0.7163677	
DETECTOR 23	OFFSETS:	-0.7559100E-01	-0.3835500E-01	0.4270600E-02	0.3437580E-01	0.5397990	0.5440425	
	GAINS:	0.5070408	0.4291074	0.3577690	0.2768829	-0.7609597	-0.7698412	
DETECTOR 24	OFFSETS:	-0.7505930E-01	-0.3621360E-01	-0.3845400E-02	0.3385480E-01	0.5394332	0.5438306	
	GAINS:	0.5010801	0.4247016	0.3534583	0.2753091	-0.7727183	-0.7818332	

Table B-3

Lamp B (Prime) - Low Gain Offsets (C_i) and Gains (D_i) for Six Cal Wedge Values

		FOR 1st VALUE	FOR 2nd VALUE	FOR 3rd VALUE	FOR 4th VALUE	FOR 5th VALUE	FOR 6th VALUE	
DETECTOR 1	OFFSETS:	-0.5037410E-01	-0.1860890E-01	0.7132600E-02	0.3375870E-01	0.5132428	0.5148496	Band 1
	GAINS:	0.3994784	0.3410130	0.2936339	0.2468260	-0.6378971	-0.6408542	
DETECTOR 2	OFFSETS:	-0.4925510E-01	-0.1736830E-01	0.7233600E-02	0.3321610E-01	0.5122850	0.5138967	
	GAINS:	0.4148498	0.3535858	0.3063182	0.2563942	-0.6640353	-0.6671127	
DETECTOR 3	OFFSETS:	-0.5137230E-01	-0.1975810E-01	0.9809800E-02	0.3239550E-01	0.5137580	0.5151665	
	GAINS:	0.4072016	0.3481600	0.2929401	0.2507598	-0.6482154	-0.6508459	
DETECTOR 4	OFFSETS:	-0.4935090E-01	-0.1889950E-01	0.7552100E-02	0.3247990E-01	0.5133566	0.5148619	
	GAINS:	0.4148422	0.3563626	0.3055648	0.2576932	-0.6657859	-0.6686767	
DETECTOR 5	OFFSETS:	-0.5100680E-01	-0.1885540E-01	0.7868900E-02	0.3468700E-01	0.5129884	0.5142983	
	GAINS:	0.4120424	0.3511810	0.3005557	0.2498288	-0.6555841	-0.6580436	
DETECTOR 6	OFFSETS:	-0.4957090E-01	-0.1917420E-01	0.7952300E-02	0.3222310E-01	0.5134971	0.5150726	
	GAINS:	0.4107260	0.3529854	0.3014650	0.2553845	-0.6587762	-0.6617688	
DETECTOR 7	OFFSETS:	-0.5339620E-01	-0.2134640E-01	0.1028790E-01	0.4057[illegible]	0.5102282	0.5136505	Band 2
	GAINS:	0.3722690	0.3180521	0.2645379	0.2133024	-0.5611859	-0.5469752	
DETECTOR 8	OFFSETS:	-0.5284440E-01	-0.2093220E-01	0.9033300E-02	0.3870700E-01	0.5113385	0.5151971	
	GAINS:	0.3760740	0.3214008	0.2700628	0.2200414	-0.5905040	-0.5971149	
DETECTOR 9	OFFSETS:	-0.5240090E-01	-0.1991050E-01	0.1153540E-01	0.3671770E-02	0.5103191	0.5137388	
	GAINS:	0.3780433	0.3219748	0.2677090	0.2242520	-0.5938[illegible]7	-0.5989401	
DETECTOR 10	OFFSETS:	-0.5271360E-01	-0.2110650E-01	0.1046320E-01	0.4201610E-01	0.5090710	0.5122694	
	GAINS:	0.3762394	0.3220329	0.2678906	0.2137770	-0.5672270	-0.5927122	
DETECTOR 11	OFFSETS:	-0.5363690E-01	-0.2252990E-01	0.6717800E-02	0.3932520E-01	0.5122315	0.5158919	
	GAINS:	0.3609101	0.3099493	0.2587582	0.2086159	-0.5661186	-0.5721151	
DETECTOR 12	OFFSETS:	-0.5340150E-01	-0.2176900E-01	0.9007800E-02	0.3923330E-01	0.5113417	0.5155867	
	GAINS:	0.3669298	0.3141873	0.2628717	0.2124733	-0.5746930	-0.5817708	
DETECTOR 13	OFFSETS:	-0.5633750E-01	-0.2146400E-01	0.9054400E-02	0.3930820E-01	0.5126416	0.5165965	Band 3
	GAINS:	0.4018272	0.3389892	0.2839987	0.2294848	-0.6237607	-0.6305326	
DETECTOR 14	OFFSETS:	-0.5565900E-01	-0.2301500E-01	0.9313500E-02	0.3859700E-01	0.5137771	0.5169862	
	GAINS:	0.4104207	0.3501585	0.2904791	0.2364209	-0.6407773	-0.6467015	
DETECTOR 15	OFFSETS:	-0.5909790E-01	-0.2957550E-01	0.2990700E-02	0.3609760E-01	0.5230393	0.5265452	
	GAINS:	0.4111196	0.3573589	0.2980555	0.2377676	-0.6489586	-0.6553429	
DETECTOR 16	OFFSETS:	-0.5890460E-01	-0.2356640E-01	0.8523200E-02	0.3598600E-01	0.5172936	0.5206682	
	GAINS:	0.4195329	0.3538085	0.2941260	0.2430456	-0.6521198	-0.6583961	
DETECTOR 17	OFFSETS:	-0.5729180E-01	-0.2311620E-01	0.1103720E-01	0.3762870E-01	0.5140637	0.5176793	
	GAINS:	0.4250826	0.3602161	0.2953913	0.2449197	-0.6593733	-0.6602356	
DETECTOR 18	OFFSETS:	-0.5744090E-01	-0.2166710E-01	0.9675900E-02	0.3829170E-01	0.5138956	0.5172643	
	GAINS:	0.4148560	0.3486704	0.2906130	0.2376407	-0.6427722	-0.6490080	
DETECTOR 19	OFFSETS:	-0.7643870E-01	-0.3634200E-01	-0.1703500E-02	0.3293920E-01	0.5399743	0.5415704	Band 4
	GAINS:	0.4644912	0.3878804	0.3216975	0.2555075	-0.7132646	-0.7163138	
DETECTOR 20	OFFSETS:	-0.7675450E-01	-0.3728760E-01	-0.2027100E-02	0.3228370E-01	0.5409477	0.5428379	
	GAINS:	0.4657200	0.3902111	0.3227499	0.2571054	-0.7160860	-0.7197023	
DETECTOR 21	OFFSETS:	-0.7632510E-01	-0.3855000E-01	-0.1967000E-02	0.3442040E-01	0.5398456	0.5425785	
	GAINS:	0.4301274	0.3632604	0.2985036	0.2340937	-0.6605740	-0.6654124	
DETECTOR 22	OFFSETS:	-0.7966350E-01	-0.3861690E-01	-0.3831400E-02	0.3020800E-01	0.5452145	0.5466886	
	GAINS:	0.4643362	0.3869625	0.3213909	0.2572265	-0.7135698	-0.7163477	
DETECTOR 23	OFFSETS:	-0.7559100E-01	-0.3835500E-01	-0.4270600E-02	0.3437560E-01	0.5397990	0.5440425	
	GAINS:	0.5070408	0.4291074	0.3577690	0.2768829	-0.7604597	-0.7898412	
DETECTOR 24	OFFSETS:	-0.7505930E-01	-0.3821360E-01	-0.3845400E-02	0.3385480E-01	0.5394332	0.5438306	
	GAINS:	0.5010801	0.4247016	0.3534583	0.2753091	-0.7727181	-0.7618332	

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APPENDIX C

TM DATA PROCESSING CONSTANTS

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APPENDIX C

TM DATA PROCESSING CONSTANTS

C1 MIRROR POSITION PROFILES

The prelaunch mirror position profiles are specified by fifth-order polynomials. The along and across scan polynomial profile coefficients for the various operating modes of the Landsat-D scan mirror are provided in Table C-1. The across scan profile is derived from the scan line corrector profile and scan mirror across scan linearity. The forward scan profile polynomials start at scan-start and end at scan-end. The reverse profile polynomials start at scan-end and end at scan-start. Scan time has been normalized to 0.060743 seconds. A second-order correction, which is based on the first-half and second-half scan-time error, must be applied to these profiles. This scan-error information is included in the TM wideband data.

The scan-line corrector velocity profile will be the same for forward and reverse scan mirror assembly scans, and is also defined by a fifth-order polynomial. Data concerning scan-line corrector profiles are not currently available.

C2 TM ANGULAR CHARACTERISTICS

The TM midscan pulse is nominally the instrument optical axis. Start- and end-scan pulses are at midscan ±7.695 and ±0.0667 degrees (object space), respectively. The forward and reverse scan angle monitor pulses are obtained from the same sensor but may be offset by one IFOV nominal. The active scan amplitude will be measured to an accuracy of 10 microradians with a repeatibility of 0.2 microradians. The nominal along-scan distance from the pixel of minor frame 7 of one band in the forward scan to the pixel of minor frame 7 of the same band in the reverse scan is (6320 -14) 6306 IFOV's.

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Table C-1
Scan-Mirror Profile Along- and Cross-Scan Data Summary
for TM Protoflight Unit (Landsat-D)

	FORWARD Polynomial Coefficients						REVERSE Polynomial Coefficients						Scan Angles	
	a_0	a_1	a_2	a_3	a_4	a_5	b_0	b_1	b_2	b_3	b_4	b_5	Start to Mid (FWD)	Mid to End (FWD)
SME-1 SAM Mode Along Scan	3.5702e-7	2.1869e-3	2.6079e-1	1.1629e+1	2.2138e+2	1.4967e+3	5.091e-7	3.7036e-3	-3.2443e-1	1.2888e+1	-2.2970e+2	1.4638e+3	67157	67175
SME-2 SAM Mode Along Scan	1.3649e-7	-2.3408e-3	2.6000e-1	-1.1438e-1	2.1761e+2	-1.4707e+3	4.0266e-7	3.6771e-3	-3.2999e-1	1.3183e+1	-2.3509e+2	1.4999e+3	67171	67195
SME-1 Cross Scan	3.3395e-7	5.9110e-5	-0.4933e-4	-9.9086e-3	9.7717e-2	1.1866e-1	2.2088e-7	7.2290e-5	-1.7248e-3	1.3948e-2	-2.7076e-2	-1.1315e+0	N/A	N/A
SME-2 Cross Scan	2.7113e-7	2.7470e-5	1.1813e-3	-9.7359e-2	1.4848e+0	-0.2997e+0	4.5580e-7	6.3702e-5	-1.0284e-3	-1.6645e-2	5.2138e-1	-4.4405e+0	N/A	N/A
Units	μrad	μrad/sec	μrad/sec^2	μrad/sec^3	μrad/sec^4	μrad/sec^5	μrad	μrad/sec	μrad/sec^2	μrad/sec^3	μrad/sec^4	μrad/sec^5	μrad	μrad

NOTE: SME is Scan Mirror Electronics
SAM is Scan Angle Monitor

The channel delay time (electronic delay between detection and analog/digital conversion) is nominally 11 microseconds for the reflective bands. However, the variability between detectors is significant and will require calibration. The thermal band delay is not yet known.

C3 DETECTOR RESPONSE DATA

Detector response data are not currently available.

C4 TM PIXEL DIMENSIONS

The nominal scale of input interpixel and interline distances are 30m each (i.e., 30 x 30 m pixels).

APPENDIX D

IMPROVED INTERRANGE VECTOR (IIRV) MESSAGE

APPENDIX D

IMPROVED INTERRANGE VECTOR (IIRV) MESSAGE

The IIRV message in Figure D-1 shall be coded in USASCII. All data fields are right justified, with leading zeros added as needed. A positive sign (+) shall be indicated by a blank, and a negative sign (-) shall be indicated by a minus. The IIRV message shall contain spacecraft position and velocity for the given epoch time. Table D-1 contains IIRV message body data field explanations.

Vector epoch times will be provided four times daily, at 00:00, 06:00, 12:00 and 18:00 GMT.

```
Line 1:  _ _ _ _ _ _ CR CR LF LF (optional message text)

Line 2:  G I I R V A R R R R CR CR LF LF
         start of     destination
         message      routing
                      indicator

                 S S S S
                 I I I I
Line 3:  V S T C C C C C B B N N N D O Y H H M M S S S S S C C C CR CR LF LF

Line 4:  S X X X X X X X X X X X X S Y Y Y Y Y Y Y Y Y Y Y Y S Z Z Z Z Z Z Z Z Z Z Z Z
         C C C CR CR LF LF

Line 5:  S X X X X X X X X X X X X S Y Y Y Y Y Y Y Y Y Y Y Y S Z Z Z Z Z Z Z Z Z Z Z Z
         C C C CR CR LF LF

Line 6:  M M M M M M M M A A A A A K K K K S M M M M M M M C C C CR CR LF LF

Line 7:  I T E R M Δ O O O O CR CR LF LF
         end of        originator
         message       routing
                       indicator
```

Figure D-1. IIRV Message Body Format

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Table D-1
IIRV ASCII TTY Message Body Explanation

Line	Characters	Explanation
1	-----	Optional message text.
2	GIIRV	Start of message (fixed).
	A	Alphabetic character indicating originator of message: blank = GSFC Z = WLPS E = ETR L = JPL W = WTR J = JSC P = PMR A = AFSCF K = KMR
	RRRR	Destination routing indicator. Specifies the site for which the message was generated. If for more than one station, this field should contain "MANY" [illegible]
3	V (Not Used)	Vector type: 1 = Free flight (routine). 2 = Forced (special update). 3 = Forced (no burn). 4 = Maneuver ignition. 5 = Maneuver cutoff. 6 = Reentry. 7 = Powered flight. 8 = Spare. 9 = Spare.
	s (Not Used)	Source of data: 1 Nominal. planning. 2 Real-time. 3 Off-line. 4 Off-line mean.
	T (Always 1)	Transfer type: 1 Interrange. 2 Intercenter.
	C (Always 1)	Coordinate system: 1 Geocentric Greenwich Rotation. (all interrange vectors) 2 Aries mean of 1950. (all intercenter vectors)
	SIC (4 characters)	Support Identification Code. Landsat-D=1294, Landsat-D'=1419
	BB (Always 1)	Body number/VID (00-99).

Table D-1 (Continued)

Line	Characters	Explanation
3 (cont)	NNN	Counter number indicating vector transfer number on a per station per transmission basis.
	DOY	Day of year.
	HHMMSSSSS	Vector epoch in GMT with resolution to nearest millisecond.
	CCC	Checksum of preceding characters: 0 through 9 = Face value Minus (-) = 1 Plus (+) = 0
4	S	Sign character: (Minus: - Plus : blank)
	XXXXXXXXXXXX	X component of position (meters).
	YYYYYYYYYYYY	Y component of position (meters).
	ZZZZZZZZZZZZ	Z component of position (meters).
	CCC	Checksum of previous characters: 0 through 9 = face value. Minus (-) = 1. Plus (+) = 0.
5	S	Sign character.
	XXXXXXXXXXXX	X-velocity component.
	YYYYYYYYYYYY	Y-velocity component.
	ZZZZZZZZZZZZ	Z-velocity component. Note All velocity components are in meters/second with resolution to nearest 1/1000 meter/second.
	CCC	Checksum of preceding characters: 0 through 9 = Face value. Minus (-) = 1. Plus (+) = 0.

Table D-1 (Continued)

Line	Characters	Explanation
6	MMMMMMMMM	Mass of target (kilograms with resolution to 1/10 of kilogram) for intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	AAAAA	Average target cross-sectional area (meters squared with resolution to nearest square centimeter) for intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	KKKK	Drag factor (dimensionless) (two digits to left of decimal point). For intercenter vector transfers and off-line (GSFC) vectors. Contains all zeroes when not used.
	S	Sign character for mean motion rate. Positive sign denoted by a space or blank. Negative denoted by minus sign.
	MMMMMMM	Mean motion rate (revolutions/day) no digits to left of decimal point. Primarily intended for GSFC off-line support. Contains all zeroes when not used.
	CCC	Checksum of preceding characters: 0 through 9 = Face value. Minus (-) = 1 Plus (+) = 0
7	ITERM	End of message.
	0000	Originator routing indicator.

APPENDIX E

TM MIDSCAN CORRECTION SUMMARY

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This appendix explains how a parabola is added to a smoothed profile polynomial to create a ground calibrated profile polynomial. This is a simplified algorithm that does not include effects from spacecraft jitter. Referring to Figure E-1, the upper curve illustrates an original smoothed profile that is normalized to the ideal scan time of 60743 μseconds. Its midscan value is defined as the profile (reference) offset angle $\emptyset_{fo}$. This value is found during the data collection for the scan used when the original profile is taken. The second figure illustrates the actual profile for scan "i" in relation to the smoothed profile. The offset angle $\emptyset_{fi}$ is found from line length code. The "ith" scan differs from the smoothed profile by a parabola where the midscan amplitude is $(\emptyset_{fi} - \emptyset_{fo}) = \Delta_{fi}$. The lowest figure illustrates the original smoothed profile, the parabola, $\Delta(t)$, and the ground calibrated profile that is the parabola added to the original profile.

Figure E-2 gives the profile polynomial modifications equations. The initial forward profile is a fifth-order power series with coefficients a_0 through a_5 defined for the ideal scan time. This initial profile is first adjusted to the actual scan time. The parabola for scan "i" is a second-order power series consisting of two terms, $a'_{1,i}$ and $a'_{2,i}$. The ground-calibrated profile is defined as the adjusted fifth-order power series with

$$a_{1,i} = a_1 \left(\frac{t_I}{t_s}\right) + a'_{1,i} \text{ and } a_{2,i} = a_2 \left(\frac{t_I}{t_s}\right)^2 + a'_{2,i}.$$

The line length code, illustrated in Figure E-3, contains first-half and second-half scan errors E1 and E2, which are defined as R1-T1 and R2-T2, respectively, where R and T represent references and half-scan times. R1 equals 30371.4 μsec and R2 equals 30371.6 μsec

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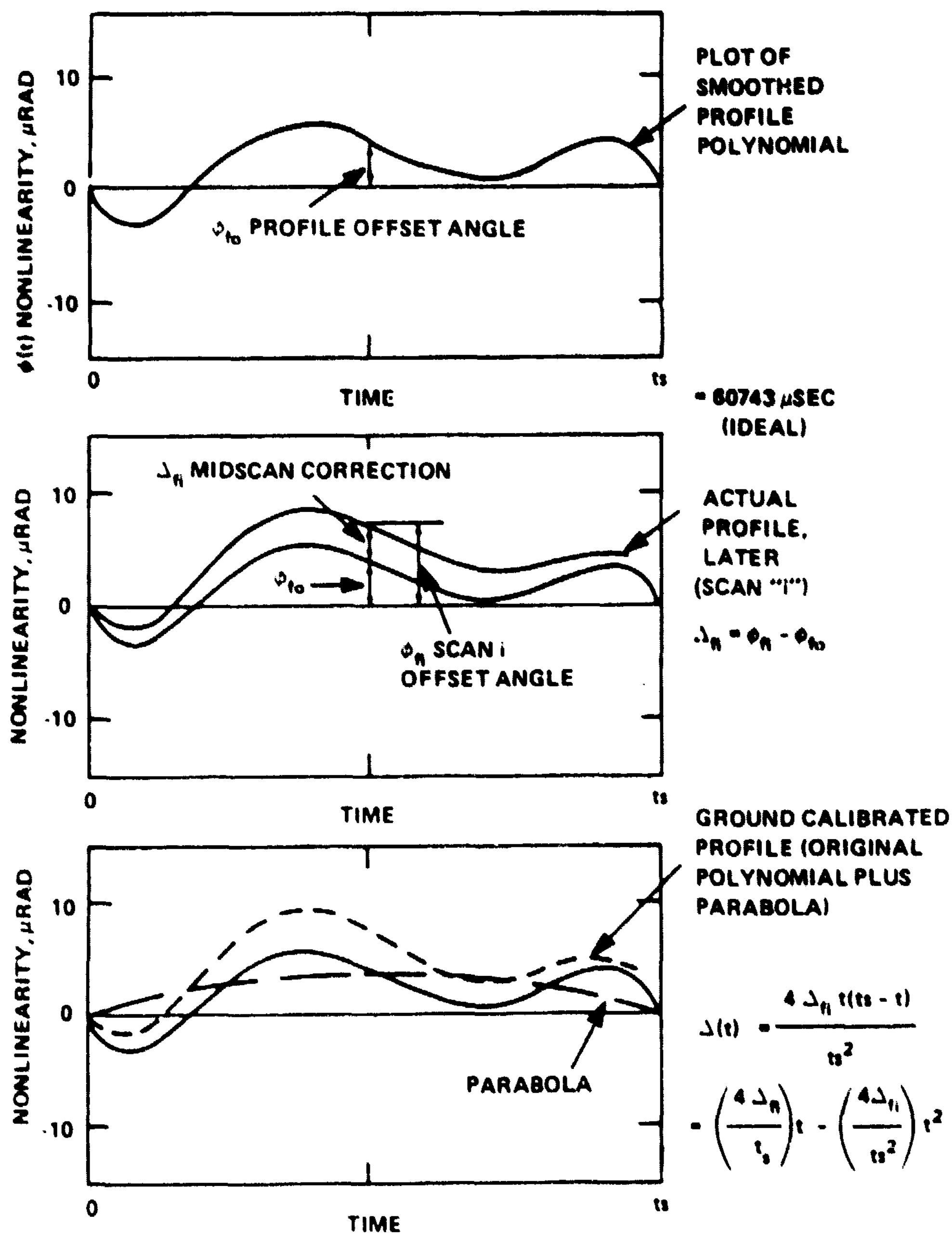


Figure E-1. Profile Polynomial Modification Curves

- INITIAL SMOOTHED PROFILE POLYNOMIAL

For ideal scan time, t_I:

$$\phi(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$$

- ADJUSTED SMOOTH PROFILE POLYNOMIAL

For actual scan time t_s:

$$\theta_A(t) = a_0 + a_1 \left(\frac{t_I}{t_s}\right) t + a_2 \left(\frac{t_I}{t_s}\right)^2 t^2 + a_3 \left(\frac{t_I}{t_s}\right)^3 t^3 + a_4 \left(\frac{t_I}{t_s}\right)^4 t^4 + a_5 \left(\frac{t_I}{t_s}\right)^5 t^5$$

- PARABOLA ASSOCIATED WITH LATER SCAN "i"

$$\Delta(t) = \left(\frac{4\,\Delta fi}{t_s}\right) t - \left(\frac{4\,\Delta fi}{t_s^2}\right) t^2$$

- GROUND CALIBRATED PROFILE POLYNOMIAL:

$$a_{0,i} = a_0$$

$$a_{1,i} = a_1 \left(\frac{t_I}{t_s}\right) + \left(\frac{4\,\Delta fi}{t_s}\right)$$

$$a_{2,i} = a_2 \left(\frac{t_I}{t_s}\right)^2 - \left(\frac{4\,\Delta fi}{t_s^2}\right)$$

$$a_{3,i} = a_3 \left(\frac{t_I}{t_s}\right)^3$$

$$a_{4,i} = a_4 \left(\frac{t_I}{t_s}\right)^4$$

$$a_{5,i} = a_5 \left(\frac{t_I}{t_s}\right)^5$$

- Δfi IS OBTAINED FROM LINE LENGTH CODE

Figure E-2. Profile Polynomial Modification Equations

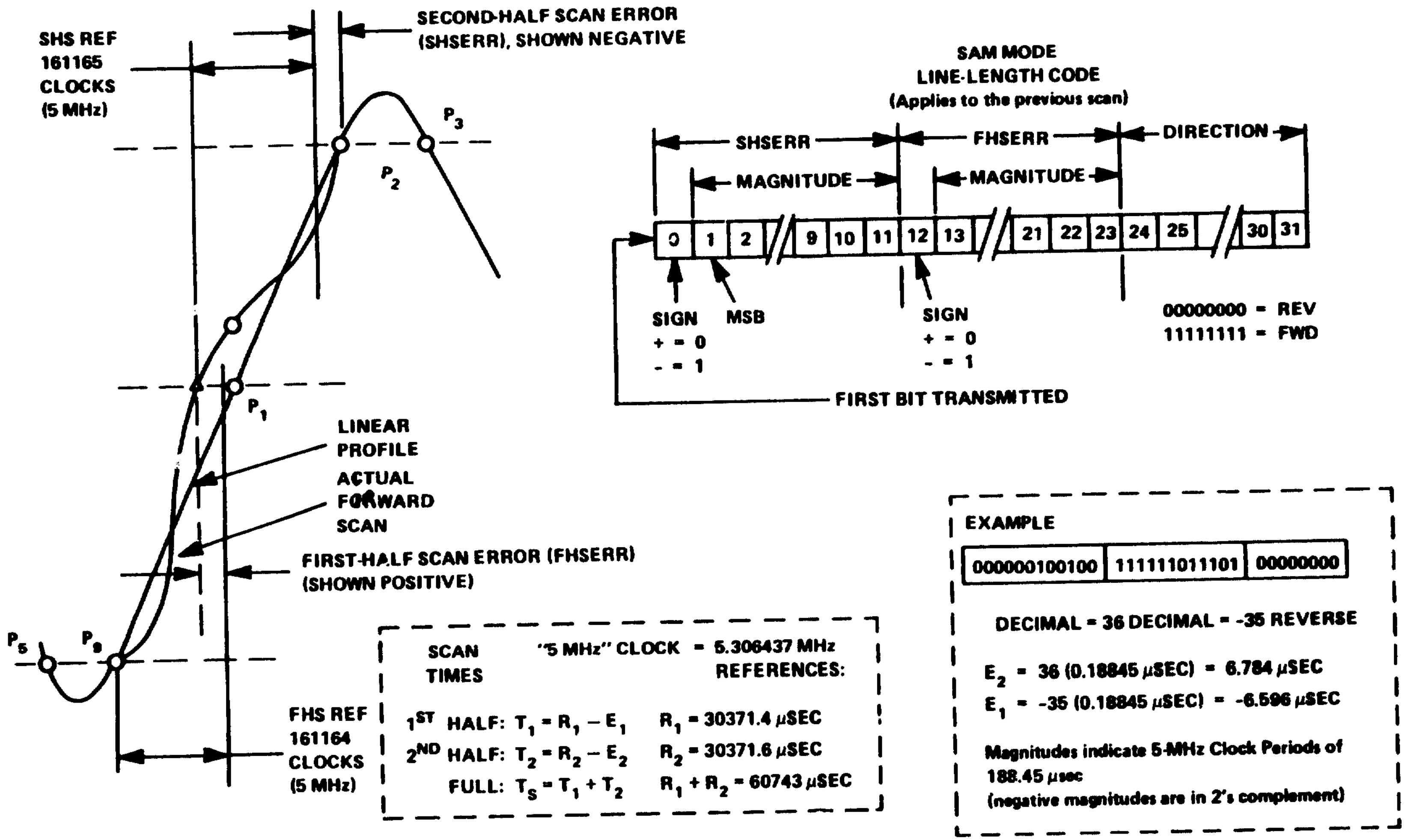


Figure E-3. Line-Length Coding (SAM Mode)

(they total the ideal scan time, t_I = 60743.0 sec). First-half scan error (FHSERR) and second-half scan error (SHSERR) have the units of 5 MHz clock periods (0.18845 sec).

These represent the errors (in clock counts) from the references in clock counts (161164 and 161165), and negative values are transmitted in binary 2's complement format as indicated. Note the example of decoding, wherein midscan time errors E1 and E2 are found, after which first- and second-half scan time T1 and T2 can be determined.

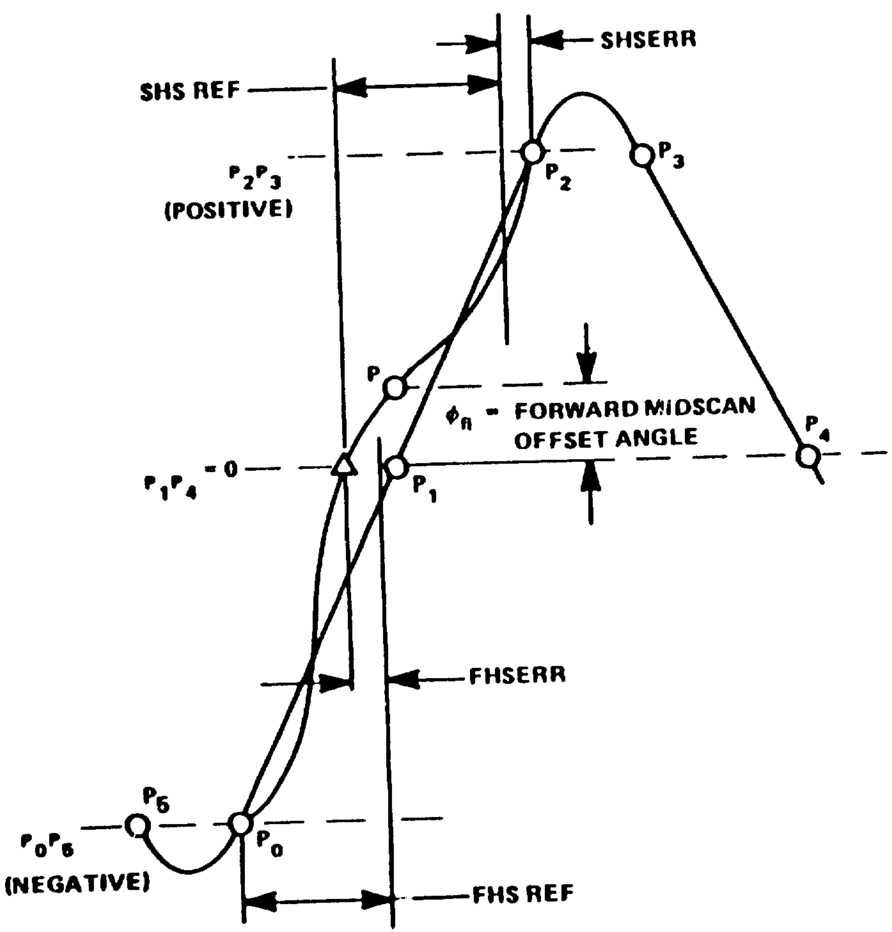
At the top right of Figure E-4 is a triangle involving the first-half scan error E1, the midscan offset angle ϕ_{fi} and the scan rate. When the actual wing mirror proportionality constant K'_o and first- and second-half scan times are taken into account, the midscan offset angle ϕ_{fi} is as indicated. Finally, $\Delta_{fi} = \phi_{fi} - \phi_{fo}$ where ϕ_{fo} was previously identified from original profiles (Figure E-1). Δ_{fi} can then be applied (Figure E-2) to the original smoothed profile polynomial to obtain the desired ground-calibrated forward scan polynomial.

Similar computations yield the reverse midscan correction Δ_{ri} and the ground calibrated reverse scan polynomial.

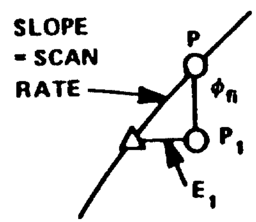
Figure E-5 is a step-by-step summary of the operations required for applying the midscan correction.

The scan profile varies slowly and requires changing no more often than every 400 scans. The maximum expected ϕ_{fi} is 100 μradian. Significant active scan time variation (from the ideal 60743 μseconds) can be expected especially when the MSS and TM instruments operate simultaneously.

Spacecraft jitter has the effect of moving the points P_0 through P_5 in inertial space. The effects of these angular motions can be



FORWARD MIDSCAN OFFSET ANGLE:



TAKING INTO ACCOUNT ACTIVE SCAN TIME (T_S) AND SAM WING MIRROR RATIO (K_0):

$$\phi_{fi} = [T_1(K_0' - 1) + T_2(K_0')] \left[\frac{\theta_{P_2P_3} - \theta_{P_0P_5}}{T_S}\right]$$

$$K_0 = \frac{-\theta_{P_0P_5}}{\theta_{P_2P_3} - \theta_{P_0P_5}}$$

FORWARD MIDSCAN CORRECTION, SCAN I

$$\Delta_{fi} = \phi_{fi} - \phi_{fo}$$

Figure E-4. Forward Offset Angle

1. DECODE FIRST AND SECOND-HALF SCAN ERRORS E_1 AND E_2, FROM LINE LENGTH CODE; COMPUTE T_1, T_2, AND TS
2. COMPUTER OFFSET ANGLE (ϕ_{fi}) FROM T_1, T_2, TS, AND K_0', $\theta_{P_0P_5}$, $\theta_{P_2P_3}$
3. COMPUTE MIDSCAN CORRECTION (Δ_{fi}) FROM OFFSET ANGLE AND ϕ_{fo}
4. COMPUTE a_1' AND a_2' FROM MIDSCAN CORRECTION
5. ADD a_1' and a_2' terms to the actual scan time adjusted smoothed PROFILE POLYNOMIAL

Figure E-5. Parabolic Midscan Correction Summary

compensated by using the outputs of Angular Displacement Sensors and the Attitude Control Gyros.